



aPriori Cost Model Guide

Version 2019 R2

Copyright

Copyright © 2019, aPriori Technologies, Inc. All rights reserved. aPriori Technologies, Inc., 300 Baker Avenue, Concord, MA 01742, USA.

Portions of this software were created under the direction of Professor Michael Philpott in the Department of Mechanical and Industrial Engineering at the University of Illinois at Urbana-Champaign.

Portions of this software copyright © 2000-2019 Tech Soft 3D.
Portions of this software copyright © 1995-2019 MySQL AB.
Portions of this software copyright © 2003-2019 Spatial Corporation.
Portions of this software copyright © 2006-2019 Siemens PLM.

The following trademarks and service marks are the property of aPriori Technologies, Inc.: aPriori, Cost Ticker, True Cost Convergence, Cost Insight.

Portions of this software contain copyrighted information of third parties. Title thereto is retained, and all rights therein are reserved, by the respective copyright owner. Third party software included with the product is identified below.

Document usage

This publication, as well as the software described in it, is provided under license and may only be used or copied in accordance with the terms of such license. The content of this publication is provided for informational use only. It is subject to change without notice and should not be construed as a commitment by aPriori Technologies, Inc. aPriori Technologies, Inc. assumes no responsibility or liability for any errors or inaccuracies that may appear in this publication.

Except as permitted by license, no part of this publication may be reproduced, stored in a retrieval system, or transmitted, in any form or by any means, without the prior written permission of aPriori Technologies, Inc.

The text and drawing set forth in this publication are the exclusive property of aPriori Technologies, Inc.

Third parties

Unless otherwise noted, all references to company names in sample text are designed solely to document the use of aPriori Technologies, Inc. products.

The brand names and product names used in this publication are the trademarks, registered trademarks, service marks, or trade names of their respective owners. aPriori Technologies, Inc. is not associated with any product or vendor mentioned in this publication unless otherwise noted.

This product includes additional third party software. All required third party and related software licenses and attribution are included with the aPriori software. For a complete list, see file "notices.txt" in the third-party-licenses sub-directory of the aPriori installation directory.

Software rights

The software is provided with Restricted Rights. Duplication by or disclosure to the U.S. Government is subject to the restrictions as set forth in FAR 12.212 and DFAR 227.7202 related to Commercial Computer Software and Commercial Computer Software Documentation, as applicable. Licensee agrees to always include such legends whenever software is, or is deemed to be, a deliverable under such a contract. The manufacturer is aPriori Technologies, Inc. with offices at 300 Baker Avenue, Concord, MA 01742.

Document Information

Last updated November 25, 2019

The latest version of this document can be found at the aPriori Support HelpCenter (requires registration): <https://support.apriori.com/hc>

CONTENTS

About This Guide	xxiv
Overview	xxv
Related documents	xxv
Typographic conventions	xxv
Feedback and customer support.....	xxvi
1 Introduction	27
2 Direct and Indirect Overhead	28
Overview	29
VPE Variables, Machine Properties, and Overhead Costs	30
Displaying and Overriding Overhead Values	31
Overhead Costs per Part.....	33
Overhead Rates	34
Annual Direct Overhead	34
Annual Depreciation	34
Annual Maintenance.....	35
Energy to Run Machine	35
Annual Supplies.....	35
Imputed Interest	36
Annual Indirect Overhead.....	36
Facilities Cost.....	36
Support Services Cost.....	37
Overhead Formula Reference.....	38
3 Root and Site Cost Model Formulas	44
Fully Burdened Cost.....	45
Piece Cost.....	46
Other Direct Costs.....	46
Amortized Investment.....	47
4 Assembly Process Group	48
Cost Model Overview	49
General Process.....	49
Part Geometry.....	53
Materials	53
Machines	53
Tooling.....	55
Feasibility and Routing	55
Adhesive Bonding Routing	56
Lock Bolt Routing	56
Threaded Insert Routing	56
Sealing Routings	56

Rivet Process Routing.....	56
Pick and Place Routing	56
Mechanical Assembly Routing	57
Welding Routing.....	57
Welding Operation Feasibility.....	58
Weld Prep Operation Feasibility	59
Material Selection	59
Machine Selection.....	59
Cost Algorithms and Calculations	60
Yields	61
Adhesive Bonding Formulas.....	62
Lock Bolt Formulas	64
Threaded Insert Formulas	66
Cap Sealing Formulas	67
Fay Sealing Formulas.....	68
Fillet Sealing Formulas	69
Rivet Process Formulas	70
Manual MIG Welding and Robotic MIG Welding.....	72
Manual TIG Welding and Robotic TIG Welding.....	84
Manual Spot Welding and Robotic Spot Welding.....	95
Electron Beam Welding Formulas.....	97
Laser Welding Formulas	100
Pick and Place Formulas.....	101
Weld Prep Calculations	103
Weld Clean Up Calculations	105
Mechanical Assembly Calculations	106
User Inputs	109
Adhesive Bonding Options	110
Lock Bolt Options	111
Threaded Insert Options	112
Cap Sealing Options	113
Fay Sealing Options	115
Fillet Sealing Options.....	116
Rivet Process Options.....	117
Pick and Place Options	118
Robotic MIG Welding Process-level Options	120
MIG Welding GCD-level Options	120
Robotic TIG Welding Process-level Options.....	122
TIG Welding GCD-level Options	123
Robotic Spot Welding Options	125
Electron Beam Welding Options	126
Laser Welding Options	127
Mechanical Assembly Options	128
Process Defaults and Thresholds	131
Assembly Welds.....	132
Pro Welds	132
Virtual Welds.....	132

Assembly Views	133
The Assembly Details Tab.....	133
Assembly Details Context Menu	134
Configurable Views	136
The Assembly Tracker Tab	136
Assembly Machining	136
5 Assembly Molding	137
Cost Model Overview for Assembly Molding.....	138
Processes for Assembly Molding.....	139
Part Geometry for Assembly Molding.....	139
Materials for Assembly Molding	139
Machines for Assembly Molding.....	140
Tooling for Assembly Molding	141
Assumptions and Limitations for Assembly Molding.....	142
Geometric Cost Drivers for Assembly Molding.....	142
Routing and Feasibility for Assembly Molding.....	144
Process Routing for Assembly Molding.....	144
Process Feasibility for Insert Injection Molding	145
Operation Assignment for Insert Pick and Place.....	146
Operation Assignment for Insert Injection Molding	147
Machine Selection for Assembly Molding.....	149
Machine Selection for Insert Pick and Place	149
Machine Selection for Insert Injection Molding.....	149
Formulas for Assembly Molding	151
Insert Pick and Place Process Formulas	151
Insert Pick and Place Operation Formulas	154
Insert Injection Molding Formulas	156
Runner Volume and Runner Area for Assembly Molding	163
Yields for Assembly Molding	164
User Inputs for Assembly Molding.....	165
Top-Level Setup Options	166
Process-level Insert Pick and Place Options.....	166
Operation-level Insert Pick and Place Options.....	167
Insert Injection Molding Options	168
Bar & Tube Fabrication Process Group	171
Cost Model Overview	172
Bar & Tube General Process.....	172
Part Geometry.....	174
Materials and Stock Forms.....	175
Machines	176
Tooling.....	180
Costing Flow.....	180
GCD Extraction	180
Feasibility and Routing	184

Cost Algorithms and Calculations	197
Yields for Bar & Tube Fabrication.....	198
Material Cost and Utilization	199
Batch Setup	201
Band Saw, Circular Saw, Reciprocating Saw.....	201
Tube Laser	203
Punching.....	205
Bar Bend Brake.....	206
Compression Bending	207
Rotary Draw Bending	208
Forming	209
Laser Cut, Oxy Fuel Cut, Plasma Cut.....	210
Shear	212
Roll Bending (2-, 3-, and 4-roll)	212
3-Roller Bending (deprecated).....	215
Extrusion	216
Billet Preheat.....	235
Die Preheat.....	236
User Inputs	238
Bar & Tube Fabrication Node Options	238
Other Setup Options	239
Extrusion Setup Options.....	240
Process Group Site Variables	242
Tube Recognition	242
Extrusion Recognition	243
Process Defaults and Thresholds	244
Material Utilization	244
Band Saw, Circular Saw, Reciprocating Saw.....	244
Tube Laser	244
Punching.....	244
Roll Bending	245
6 Casting--Die Process Group	246
Die Casting Cost Model Overview.....	247
Die Casting General Process.....	247
Part Geometry for Die Casting	247
Materials for Die Casting	248
Machines for Die Casting	248
Tooling for Die Casting	249
GCD Extraction for Die Casting.....	249
Slide Bundles for Die casting	251
Feasibility and Routing for Die Casting	251
Die Casting Process-level Routing	252
High Pressure Die Casting Operation-level Feasibility	253
Gravity Die Casting Operation-level Feasibility	255
Material Selection for Die Casting.....	257
Machine Feasibility and Selection for Die Casting	257

Cost Algorithms and Calculations for Die Casting.....	262
Yields For Die Casting	262
Material Cost and Utilization for Die Casting.....	263
Labor and Setup Costs for Die Casting	266
Gating System Model for Die Casting	267
Melting Formulas for Die Casting.....	275
Cleaning Formulas for Die Casting	279
Finishing Formulas for Die Casting.....	281
Visual Inspection Formulas for Die Casting.....	283
Design Complexity Factor.....	284
High Pressure Die Casting and Gravity Die Casting Process Formulas.....	285
Trim Formulas for Die Casting.....	288
Core Refractory Coating for Die Casting	289
Refractory Coat Oven Dry for Die Casting.....	291
Refractory Coat Air Dry for Die Casting.....	293
Required Clamp Force.....	293
Coremaking for Die Casting.....	293
Number of Mold Cavities for Die Casting.....	294
Tooling Cost for Die Casting	295
User Inputs for Die Casting	301
Casting - Die Node Inputs.....	301
Melting Process Inputs.....	301
High Pressure and Gravity Die Casting Process Inputs.....	302
Trim Process Inputs.....	305
Refractory Coating Process Inputs for Die Casting.....	307
Finishing Process Input.....	310
Design-to-cost Configuration for Die Casting	310
Material Issues: Wall Thickness Thresholds.....	311
Draft Issues: Draft Angle Thresholds.....	312
Radius Issues: Edge Radius Thresholds	313
Proximity Issues: Hole Proximity Issues	313
Hole Issues: Maximum Hole Depth.....	314
Hole Issues: Minimum Hole Diameter	314
Tolerance Grade and Roughness Ranges	315
7 Casting--Sand Process Group	316
Sand Casting Cost Model Overview.....	317
Sand Casting General Process	317
Part Geometry for Sand Casting.....	318
Materials for Sand Casting	319
Machines for Sand Casting.....	319
Tooling for Sand Casting.....	320
GCD Extraction for Sand Casting.....	320
Feasibility and Routing for Sand Casting	323
Sand Casting Process-level Routing	323
Sand Casting Process-level Feasibility.....	326
Coremaking Feasibility and Routing for Sand Casting.....	327

Sand Casting Operation-level Feasibility	332
Material Selection for Sand Casting	338
Machine Feasibility and Selection for Sand Casting.....	339
Cost Algorithms and Calculations for Sand Casting.....	345
Yields for Sand Casting	346
Material Cost and Utilization for Sand Casting	347
Labor and Setup Costs for Sand Casting.....	349
Melting Formulas for Sand Casting	351
Degating Formulas	356
Cleaning Formulas	356
Finishing Formulas	358
Visual Inspection Formulas	360
Cope Height.....	361
Design Complexity Factor.....	361
Gating System Model	363
Mold Making Formulas	372
Coremaking—All Except Stock Core.....	374
Coremaking--Stock Core.....	377
Mold Refractory Coat.....	377
Core Refractory Coat for Sand Casting.....	379
Refractory Coat Oven Dry for Sand Casting	381
Refractory Coat Air Dry for Sand Casting	383
Pour Formulas	383
Cool Formulas.....	384
Shakeout Formulas.....	385
Required Clamp Force.....	386
Number of Mold Cavities	386
Tooling Cost for Sand Casting.....	387
User Inputs for Sand Casting	391
Top-level Sand Casting Setup Options	391
Melting Setup Options	392
Coremaking Setup Options	392
Moldmaking Setup Options	393
Pour Setup Options	394
Shakeout Setup Options.....	394
Cleaning Setup Options	394
Refractory Coating Setup Options for Sand Casting	395
Finishing Setup Options	399
Process Defaults and Thresholds for Sand Casting.....	400
Customizing the Number of Core Segments.....	400
Material Utilization Variable	402
Design Complexity Variables.....	402
Hole Feasibility Variable.....	402
Machine Selection Variable.....	403
Melting Variable	403
Moldmaking Variables	403
Coremaking Variables	404

Gating System Variables.....	405
Refractory Coating Variables.....	406
Visual Inspection Variables	407
Design-to-cost Configuration for Sand Casting	407
Material Issues: Wall Thickness Thresholds.....	408
Draft Issues: Draft Angle Thresholds.....	409
Radius Issues: Edge Radius Thresholds	410
Proximity Issues: Hole Proximity Issues	411
Hole Issues: Maximum Hole Depth.....	411
Hole Issues: Minimum Hole Diameter	412
Tolerance Grade and Roughness Ranges	413
8 Composites Process Group	414
Composites Cost Model Overview	414
Composites General Process.....	414
Part Geometry for Composites	416
Materials for Composites.....	417
Machines for Composites.....	418
Tooling for Composites	420
GCD Extraction for Composites	421
Routing and Feasibility for Composites.....	423
Machine Selection for Composites	428
Ultrasonic Cut Machine Selection	428
Machine Selection for Mold Preparation, Hand Layup, and Bench Operation	429
Tool Clean Machine Selection.....	429
Automated Fiber Placement Machine Selection	430
Automated Tape Layup Machine Selection	431
Autoclave Cure Machine Selection	431
Cost Algorithms and Calculations for Composites	432
Labor-dependent and Labor-independent Tasks.....	433
Yields for Composites.....	433
Ultrasonic Cut Process	434
Ultrasonic Cutting Operation	436
Mold Preparation Process.....	438
Applying Mold Release Operation	438
Curing Mold Release Operation	439
Applying Tool Tack Operation	439
Curing Tool Tack Operation.....	440
Hand Layup Process	441
Ply Placing Operation for Hand Layup.....	442
Core Potting Operation for Hand Layup.....	445
Core Splicing Operation for Hand Layup.....	446
Core Placing Operation for Hand Layup.....	447
Debulk Component-level Operation	447
Vacuum Bag Process	448
Tool Length, Width, and Area	449
Remove Vacuum Bag Component-level Operation	450

Final Vacuum Bag Process.....	451
Vacuum Bag Drop Test Component-level Operation.....	454
Attach Thermocouples Component-level Operation.....	454
Automated Tape Layup Process.....	455
Ply Placing Operation for Automated Tape Layup.....	456
Automated Fiber Placement Process.....	460
Ply Placing Operation for Automated Fiber Placement.....	461
Ply Deformation Level.....	465
Autoclave Cure Process.....	469
Bench Operation Process.....	472
Inspecting Component-level Operation.....	473
Tool Breakdown Component-level Operation.....	474
Tool Clean Process.....	475
Manual Tool Cleaning Operation.....	476
Cryogenic Tool Cleaning Operation.....	477
Laser Tool Cleaning Operation.....	477
Overhead Calculations for Composites.....	477
User Inputs for Composites.....	479
Composites Node Option.....	479
Ultrasonic Cut Options.....	479
Mold Preparation Options.....	480
Hand Layup Options.....	481
Automated Tape Layup Options.....	482
Automated Fiber Placement Options.....	484
Autoclave Cure Options.....	485
Bench Operation Options.....	486
9 Forging Process Group	488
Forging overview.....	489
Forging processes.....	489
Forging material.....	489
Forging material composition.....	490
Forging material stocks.....	490
Controlling forging stock selection.....	490
Forging material utilization.....	491
Forging machines.....	491
Forging process routings.....	491
Forging process setup.....	492
Top-level setup options.....	492
Material stock setup options.....	492
Hammer setup options.....	493
Piece press setup options.....	493
Trim setup options.....	494
Forging costing details.....	494
10 Stock Machining and Machining Process Groups	495
Machining Overview.....	496

Material Stock and Utilization	497
Stock Machining Material Composition	497
Stock Machining Material Stock Type	498
Material Stock Alignment and Cross-section Determination.....	498
Stock Machining Material Stock Allowances	499
Stock Machining Material Utilization	500
Stock Machining Routing and Plate Stock.....	500
GCD Extraction	500
Component GCD.....	501
Hole GCD	501
Parallel Surface Chain GCD.....	502
Perimeter GCD	502
LIES_NEAR Relation	503
IS_ABOUT Relation	504
IS_FILLET_OF Relation	504
CorssSection GCD	504
Pocket GCD.....	504
Slot GCD	508
Routing and Feasibility for Machining	516
Process Routing and Feasibility for Machining	517
Machine Selection for Machining	520
Operation Routing and Feasibility for Machining	525
Multiple Approach Surface Finishing	543
Virtual Machining.....	558
Tool Selection for Machining	560
Cost Algorithms and Calculations for Machining.....	582
Feeds and Speeds in the Machining Cost Model	582
Operation Cycle Time and Cut Time Calculations	585
Chemical Milling Formulas	600
Batch Setup Time	609
Process Cycle Time	610
Expendable Tooling Costs	611
User Inputs for Machining	611
Machining Node Process Setup Options.....	612
Stock Machining Node Process Setup Option.....	620
Machining Process-level Options	621
Surface Finishing Milling Options.....	623
Hole Making Options.....	625
Rough Turning Options	627
Finish Turning Options	628
Edge Finishing Option	629
Deburring Options.....	629
Threading Options.....	634
Surface Rough Milling Options.....	635
Pocket Rough Milling Options.....	637
Slot Milling Options	640
Groove Milling Options	642

Slot Rough Milling Options.....	645
Dovetail Finishing Options	647
Bulk Milling Options	650
Keyway Broaching Options	653
Chemical Milling Options	654
Setup Operation Options	656
Material Stock Options.....	657
Design-to-cost Configuration for Machining	658
Standard Drilling Tool Diameters	658
Standard Filleting Tool Diameters.....	659
Tolerance Grade and Roughness Ranges	660
Semi-automated Costing	660
Semi-automated Costing.....	661
Diagnostic Information.....	661
Workflow.....	661
Achieving Full Costing	664
Working with Features to Review.....	666
Working with the Heat Map (Geometry Analysis).....	668
Modifying Machining Operation Assignments	671
Explicitly Assigning Operations to GCDs	672
Manually Assigned Operations	674
Working with Gears, Splines, Sprockets, and Flutes	687
Defining AxiGrooves.....	689
Overriding AxiGroove Properties	691
Using the Gear Definition Dialog.....	692
AxiGroove Geometric Properties	701
Process and Operation Routing and Feasibility for Gears.....	704
Site Variables for Gears	707
Cost Model Variables for Gears	710
Setup Options for Gears.....	711
Working with Part Setups and SetupAxis GCDs	716
Setup Operations	719
Setup Axis GCDs	719
Principal Setup Axes	720
Rotational Setup Axes	723
System-activated and User-activated Setup Axes	724
Turning Axes.....	726
Displaying Setups, Associated Operations, and GCDs.....	731
Setup Axes and Operation Feasibility	732
GCD Accessibility and Tool Orientations.....	734
GCD Accessibility and Setup Axes	736
Operation Assignment for Machining.....	740
3-Axis Mill	742
4-Axis Mill	752
5-Axis Mill	759
2-AxisLathe	766
3-AxisLathe.....	766

	Mill Turn	767
11	2-Model Machining Process Group	769
	Cost Model Overview	770
	2-Model Quick Start.....	771
	Benefits of 2-Model Machining	774
	A note about part alignment	775
	A 2-Model Machining example	776
	Cost the input source model.....	777
	Cost the finished model	779
	Transitioning to 2-Model.....	780
	2-Model GCDs.....	781
	Source model GCD	781
	Flat GCD.....	782
	GCD property “Is Stock Surface”	783
12	Sheet Metal—Hard Tooled	784
	Cost Model Overview for Hard Tooled Sheet Metal	785
	Hard Tooled Sheet Metal General Process	785
	Part Geometry for Hard Tooled Sheet Metal.....	787
	Materials and Stock Forms for Hard Tooled Sheet Metal.....	788
	Material Utilization and Part Nesting for Hard Tooled Sheet Metal.....	790
	Machines for Hard Tooled Sheet Metal	790
	Tooling for Hard Tooled Sheet Metal.....	791
	GCD Extraction for Hard Tooled Sheet Metal	796
	Blank GCD for Hard Tooled Sheet Metal.....	799
	Main Surface for Hard Tooled Sheet Metal	805
	LIES_OUTSIDE Relation for Hard Tooled Sheet Metal.....	805
	Peninsular Ratio Property for Hard Tooled Sheet Metal	806
	Cam Bundling for Hard Tooled Sheet Metal	806
	Surface-only CAD Models for Sheet Metal	807
	Routing and Feasibility for Hard Tooled Sheet Metal.....	808
	Sheet Metal Process Routings.....	808
	Operation-level Feasibility and Routing for Progressive Die	809
	How aPriori Groups Operations onto Die Stations	817
	User Inputs for Hard Tooled Sheet Metal.....	827
	Progressive die process setup.....	827
	Tandem Die Process Setup.....	845
	Design-to-cost Configuration for Sheet Metal	846
13	Sheet Metal--Hydroforming	847
	Cost Model Overview for Hydroforming	847
	General Process for Hydroforming	848
	GCDs for Hydroforming.....	849
	Material and Stock Forms for Hydroforming	849
	Material Utilization and Part Nesting for Hydroforming	850

Machines for Hydroforming.....	851
Tooling for Hydroforming.....	852
GCD Extraction for Hydroforming.....	853
Blank GCD.....	853
Xsection GCD.....	861
Ram Direction GCD.....	862
Main Surface GCD.....	865
Form GCD.....	866
StraightBend GCD.....	869
Routing and Feasibility for Hydroforming.....	869
Process Routing for Hydroforming.....	870
Operation Assignment for Hydroforming.....	872
Process Feasibility for Hydroforming.....	875
Material Stock Selection for Hydroforming.....	877
Material Stock Selection for Offline Blanking Routings.....	877
Material Stock Selection for Laser Cut and Router Cut Routings.....	877
Machine Selection for Hydroforming.....	878
Hydroform Machine Selection.....	878
Offline Blank Machine Selection.....	881
Formulas for Hydroforming.....	882
Yields for Hydroforming.....	882
Material Cost and Utilization for Hydroforming.....	883
Labor and Setup Costs for Hydroforming.....	884
Cycle Time for Offline Blanking.....	885
Cycle Time for the Hydroform Process.....	886
Expendable Tooling Cost for the Hydroform Process.....	887
User Inputs for Hydroforming.....	888
Sheet Metal – Hydrforming Options.....	888
Hydroform Fluid Cell Options.....	889
Hydroform Cycles Option.....	890
Coil Material Stock Options.....	891
Sheet Material Stock Options.....	900
Hydroform Options.....	903
Offline Blank Options.....	904
14 Sheet Metal—Transfer Die	906
Cost Model Overview for Transfer Die.....	907
Transfer Die General Process.....	907
Part Geometry for Transfer Die.....	909
Materials and Stock Forms for Transfer Die.....	909
Material Utilization and Part Nesting for Transfer Die.....	910
Machines for Transfer Die.....	911
Tooling Overview for Transfer Die.....	911
Transfer Die Quick Start.....	912
Offline Blanking.....	913
Die Station 1: Drawing.....	914

Die Station 2: Edge Trimming, Direct Piercing, and Cam Piercing	916
Die Station 3: Restriking	919
GCD Extraction for Transfer Die	921
Blank GCD	924
Ram Direction for Transfer Die	931
Main Surface for Transfer Die	934
Form GCD	935
Cam Bundling for Transfer Die	939
LIES_NEAR Relation	940
LIIES_OUTSIDE Relation	941
Surface-only CAD Models for Transfer Die	941
Tooling for Transfer Die	943
Tool Life for Transfer Die	943
Tooling Bill of Materials for Transfer Die	944
Customizing Tooling Costs for Transfer Die	947
Primary Forming for Transfer Die	950
User Inputs for Transfer Die	952
Setup Options for Transfer Die	952
Process Defaults and Thresholds for Transfer Die	968
15 Sheet Metal—Soft Tooled	971
Cost Model Overview	972
General Process	972
Part Geometry	974
Materials and Stock Forms	975
Machines	976
Tooling	979
GCD Extraction	979
Feasibility and Routing	982
Process-level Routing	982
Process-level Feasibility	983
Material Selection	984
Machine Selection	985
Operation-level Feasibility and Routing	987
Chemical Milling	990
Cost Algorithms and Calculations	1000
Material Cost and Utilization	1000
Yields for Sheet Metal	1006
Deslag	1008
Bend Brake	1008
Laser Cut, Oxy Fuel Cut, Plasma Cut	1009
Waterjet Cut	1011
Roll Bending (2-, 3-, and 4-roll)	1013
3D Laser	1015
Cut-to-Length, Shear	1015
Turret Press, Laser Punch, Plasma Punch	1016
User Inputs	1017

Top-level Process Setup Options.....	1018
Common Inputs.....	1019
Turret-Press-specific Inputs	1020
Waterjet-Cut-specific Inputs	1022
Plasma-Cut-specific Inputs	1025
Roll Bending Inputs	1025
Conical Roll Bending Inputs.....	1025
Process Defaults and Thresholds	1028
Design-to-cost Configuration for Sheet Metal	1029
Hole-to-bend Proximity Thresholds	1029
Hole-to-blank Proximity Thresholds.....	1030
Hole-to-form Proximity Thresholds	1030
Hole-to-hole Proximity Thresholds	1031
Bend Issue Threshold	1031
16 Sheet Metal—Stretch Forming	1032
Stretch Forming Overview.....	1033
Stretch Forming Processes	1033
Transverse and Longitudinal Stretch Forming	1034
Stretch Forming Geometry	1037
Stretch Forming Materials and Stock Forms.....	1038
Stretch Forming Machines	1038
Stretch Forming Tooling.....	1038
GCD Extraction for Stretch Forming.....	1039
Blank GCD.....	1039
Xsection GCDs	1040
Ram Direction GCD.....	1043
Form GCDs.....	1043
Routing for Stretch Forming	1044
Process Feasibility for Stretch Forming.....	1046
Stretch Form Process Feasibility	1046
Xsection Curve Height for Stretch Forming.....	1046
Machine Selection for Stretch Forming	1048
Cold Storage Machine Selection	1048
Stretch Form Machine Selection	1048
Bench Operation Machine Selection.....	1051
Router Machine Selection.....	1051
Material Stock Selection for Stretch Forming	1052
Formulas for Stretch Forming.....	1053
Yields for Stretch Forming.....	1053
Material Cost and Utilization for Stretch Forming	1054
Labor and Setup Costs for Stretch Forming	1056
Cycle Time for the Stretch Form Process	1056
Expendable Tooling Cost for the Stretch Form Process.....	1058
Formulas for the Bench Operation Process	1058
Formulas for the Cold Storage Process	1059
Formulas for the Router Process.....	1059

User Inputs for Stretch Forming	1060
Setup Options for Sheet Metal – Stretch Forming	1060
Setup Options for Stretch Forming Cycles	1061
Setup Option for Cold Storage	1062
Setup Options for Bench Operation	1062
Setup Options for Router	1063
Process Defaults and Thresholds for Stretch Forming	1063
17 Plastic Molding Process Group	1065
Cost Model Overview	1066
General Process for Plastic Molding	1066
Part Geometry for Plastic Molding	1067
Materials for Plastic Molding	1067
Machines for Plastic Molding	1068
Tooling for Plastic Molding	1068
Costing Flow	1069
GCD Extraction for Plastic Molding	1069
How aPriori Selects Draw Direction fir Plastic Molding	1071
How aPriori Assigns Holes and Voids to Slides and Lifters	1075
Feasibility and Routing	1082
Cost Algorithms and Calculations	1087
Primary Direct Costs for Plastic Molding	1087
Other Direct Costs for Plastic Molding	1088
Material Utilization for Plastic Molding	1089
Times for Plastic Molding	1091
Nominal Wall Thickness	1097
Required Shot Size	1097
Required Clamp Force	1098
Cavity Orientation	1099
Dimensions of the Plastic Forming Region	1101
Number and Layout of Mold Cavities	1102
Runner System Model	1104
Other Calculations	1115
Tooling Cost	1115
User Inputs for Plastic Molding	1120
Process Defaults and Thresholds	1125
Design-to-cost Configuration for Plastic Molding	1128
Material Issues: Wall Thickness Thresholds	1129
Draft Issues: Draft Angle Thresholds	1130
Radius Issues: Minimum Internal and External Edge Radius	1130
Proximity Issues: Hole Proximity Issues	1131
Hole Issues: Length-to-diameter (L/D) Ratio	1131
18 Powder Metal Process Group	1132
Powder metal overview	1133
Powder metal processes	1133
Powder metal material	1133

	Powder metal material utilization	1134
	Powder metal machines	1134
	Powder metal process routings	1135
	Powder metal process setup options	1135
	Powder metal costing details.....	1136
19	Rotational and Blow Molding Process Group	1138
	Rotational and blow molding overview	1139
	Rotational and blow molding processes	1139
	Rotational and blow molding material	1139
	Rotational and blow molding material composition.....	1139
	Rotational and blow molding material utilization	1140
	Rotational and blow molding machines.....	1140
	Rotational molding process setup	1140
	Number of drop boxes	1140
	Number of labels applied to one part.....	1141
	Cost per label applied to the part	1141
	Expected part shrinkage percentage	1141
	Mold length margin.....	1141
	Mold width margin.....	1141
	Mold height margin.....	1141
	Mold spacing margin.....	1141
	Total number of molds used	1142
	Colorant.....	1142
	Enable part mirroring.....	1142
	Blow molding process setup.....	1142
	Number of machine operators.....	1142
	Number of labels applied to one part.....	1142
	Cost per label applied to the part	1143
	Maximum wall thickness.....	1143
	Mold temperature.....	1143
	Rotational and blow molding costing details	1143
20	Sheet Plastic Process Group	1145
	Sheet plastic overview.....	1146
	Sheet plastic routings	1146
	Sheet plastic processes	1148
	Material conversion processes	1148
	Thermoforming processes	1149
	Router process	1152
	Sheet plastic material	1152
	Sheet plastic material unit cost.....	1152
	Sheet plastic material composition.....	1153
	Sheet plastic material utilization.....	1153
	Sheet plastic machines	1153
	Sheet plastic costing details	1154

21	Additive Manufacturing Process Group	1155
	Process Routing for Additive Manufacturing	1156
	Materials for Additive Manufacturing	1158
	Process Feasibility for Additive Manufacturing	1159
	Machine Selection for Additive Manufacturing	1160
	Machine Feasibility for Printing	1160
	Machine Feasibility for Laser Sintering	1161
	Machine Feasibility for Metal Sintering	1161
	Machine Feasibility for Resin Curing	1161
	Machine Feasibility for Part Curing	1162
	Additive Manufacturing Formulas	1162
	Accounting Formulas for Additive Manufacturing	1163
	Yield Formulas for Additive Manufacturing	1163
	Printing Formulas	1164
	Laser Sintering Formulas	1171
	Metal Sintering Formulas	1178
	Resin Curing Formulas	1188
	Breakoff Formulas	1195
	Power Tool Base Removal Formulas	1198
	Cleaning Formulas	1199
	Part Curing Formulas	1199
	Sieving Formulas	1201
	Powder Loading Formulas	1202
	User Inputs for Additive Manufacturing	1202
	Using the Build Direction Tool to Orient the Part	1202
	Top-level Setup Option	1204
	Printing Setup Options	1204
	Laser Sintering Options	1206
	Metal Sintering Options	1209
	Resin Curing Options	1212
	Part Curing Option	1213
	Sieving Option	1214
	Powder Loading Option	1214
22	Heat Treatment Process Group	1215
	Heat Treatment Overview	1216
	Heat Treatment Processes	1216
	Heat Treatment Machines	1216
	Heat Treatment Process Routings	1217
	Heat Treatment Process Setup	1217
	Hot Isostatic Pressing	1218
	Process Routing and Feasibility for Hot Isostatic Pressing	1218
	Machine Selection for Hot Isostatic Pressing	1218
	Formulas for Hot Isostatic Pressing	1220
	Setup Options for Hot Isostatic Pressing	1226
	Heat Treatment Costing Details for Other Processes	1228

23	Surface Treatment Process Group	1229
	Surface Treatment Cost Model Overview	1230
	Surface Treatment Feasibility and Routing	1230
	Surface Treatment Routing	1231
	Surface Treatment Feasibility	1235
	Surface Treatment Machine Selection.....	1236
	Cost Algorithms and Calculations	1240
	Surface Treatment Accounting Calculations.....	1240
	Surface Treatment Yield Calculations	1241
	Bead Blast and Sand Blast Formulas	1242
	Shot Blast Formulas.....	1242
	Shot Peen Formulas	1243
	Painting Formula	1244
	Passivation formulas	1244
	Powder Coat Cart Formulas	1246
	Wet Coat Line Formulas	1248
	Screen Printing Formulas	1250
	Plating Process Formulas	1251
	Degrease Formulas.....	1252
	Mask Spray Formulas	1254
	Mask Bench Formulas	1255
	Anodize Formulas.....	1257
	Vibratory Finishing Formulas	1262
	User Inputs	1268
	Shot Peen Process Inputs	1268
	Plating Processes Inputs.....	1268
	Degrease Inputs	1269
	Manual Paint Inputs	1270
	Powder Coat Cart Inputs	1272
	Screen Printing Inputs.....	1273
	Wet Coat Line Inputs.....	1274
	Passivation Inputs	1275
	Mask Spray Inputs	1275
	Anodize Inputs	1276
	Vibratory Finishing Inputs	1277
	Process Defaults and Thresholds	1280
24	Other Secondary Processes Process group	1281
	Packaging Processes.....	1282
	Packaging overview.....	1282
	Packaging machines	1282
	Packaging process routings	1283
	Packaging process setup	1283
	Packaging costing details	1284
	Cleaning Process	1284
	Ultrasonic Cleaning	1284

Testing and Inspection Processes	1286
CMM Inspection	1287
CT Scan	1290
Fluorescent Penetrant Testing	1291
Hydrostatic Leak Testing	1292
Magnetic Penetrant Testing	1292
Xray Inspection Process	1293
25 User Guided Costing	1294
Overview	1295
Benefits of User-guided Costing	1295
User-guided VPEs and Processes	1295
User-guided Costing Steps	1296
Detailed Information on User-guided Cost Models	1296
Creating or Opening a Virtual Part	1296
Using Settings from a Start Part	1299
Entering Production Information	1301
Entering Geometric Information	1302
Administering Start Parts	1305
26 User Guided Injection Molding	1308
Cost Model Overview	1309
General Process	1309
Part Geometry	1310
Materials and Stock Forms	1310
Machines	1311
Tooling	1311
Geometric User Inputs	1312
Part Volume	1314
Part Length, Width, and Height	1315
Part Surface Area, Projected Area and Perimeter, and Wall Thickness	1317
Undercut Depths	1318
Number of Lifters, Inserts and Unscrewing Mechanism	1320
Feasibility and Routing	1321
Process-level Feasibility and Routing	1321
Machine Feasibility and Selection	1321
Cost Algorithms and Calculations	1322
Primary Direct Costs	1323
Other Direct Costs	1323
Yields	1324
Material Utilization	1325
Times	1326
Nominal Wall Thickness	1327
Required Shot Size	1327
Required Clamp Force	1327
Number of Mold Cavities	1328
Mold Dimensions	1330

Tooling Cost.....	1332
Additional User Inputs	1336
Process Defaults and Thresholds	1338
27 User Guided Sheet Metal—Progressive Die	1340
Cost Model Overview	1341
General Process.....	1341
Part Geometry.....	1341
Materials	1342
Machines	1343
Tooling.....	1343
Geometric Inputs	1343
User Guided Costing Node	1346
Sheet Metal PG Node.....	1347
Progressive Die Routing Node.....	1349
Progressive Die Node	1353
Feasibility and Routing	1359
Process-level Feasibility	1359
Material Selection	1360
Machine Selection	1360
Cost Algorithms and Calculations	1363
Material Cost and Utilization	1363
Accounting Calculations	1365
Cycle Time Calculation	1366
Tooling Calculation.....	1366
Additional User Inputs	1372
Trim Strip Applied to Length and Width of Part	1372
Width of Addendum Added to Blank Size [per side].....	1373
Maximum Strip Width.....	1373
Minimum Strip Width.....	1373
Number of Parts Stamped Concurrently.....	1374
Blank XY Orientation within Part Strip	1374
Pierce Before or After Forms	1374
Press Carrier Strip Type.....	1374
Single Edge Carrier Strip Width.....	1375
Double Edge Carrier Strip Width.....	1376
Pitch Margin Adder for Center Carrier Strip Type.....	1376
Press French Stop.....	1377
Coil Pitch.....	1377
Coil Width.....	1377
Process Defaults and Thresholds	1379
28 User Guided Sheet Metal—Stage Tooling	1380
Cost Model Overview	1381
General Process.....	1381
Part Geometry.....	1381

Materials	1382
Machines	1383
Tooling.....	1383
Geometric Inputs	1383
User Guided Node	1386
Sheet Metal PG Node.....	1386
Stage Tooling Routing Node.....	1389
Stage Tooling Node	1393
Feasibility and Routing	1396
Process-level Feasibility	1396
Material Selection	1397
Machine Selection	1397
Cost Algorithms and Calculations	1399
Material Cost and Utilization	1399
Accounting Calculations	1401
Cycle Time Calculation	1401
Tooling Calculation.....	1401
Additional User Inputs	1407
Width of Addendum Added to Blank Size [per side].....	1407
Stock Length Margin	1407
Stock Width Margin.....	1407
Process Defaults and Thresholds	1408
29 User Guided Sheet Metal—Turret Press	1409
Cost Model Overview	1410
General Process.....	1410
Part Geometry.....	1410
Materials	1411
Machines	1412
Tooling.....	1412
Geometric Inputs	1412
User Guided Costing Node	1415
Sheet Metal PG Node.....	1416
Turret Press Routing Node	1418
Turret Press Node	1420
Bend Brake Node	1426
Summary Table.....	1427
Feasibility and Routing	1430
Process-level Feasibility	1430
Material Selection	1432
Machine Selection	1432
Cost Algorithms and Calculations	1434
Yields	1434
Turret Press Material Cost and Utilization	1435
Turret Press Accounting Calculations.....	1436
Bend Brake Accounting Calculations.....	1436

	Turret Press Cycle Time Calculation	1437
	Turret Press Expendable Tooling Costs	1441
	Bend Brake Cycle Time Calculation	1441
	Process Defaults and Thresholds	1443
30	Wire Harness Process Group	1444
	Cost Model Overview	1445
	General Process.....	1446
	Cost Driver Extraction	1450
	To import and cost a new wire harness.....	1451
	To validate your initial costing	1453
	Cost Algorithms and Calculations	1455
	Material Cost Calculations	1455
	Cutting and Stripping (User Guided)	1455
	Wire Termination	1456
	Connector Assembly	1457
	Splice	1458
	Harness Layout.....	1458
	Branch Covering	1459
	Braid	1460
	Label	1460
	Test.....	1460
	User Inputs	1462
	Process Defaults and Thresholds	1465
	Process Limitations:	1470
31	PCBA Process Group	1471
	PCBA Cost Model Overview	1472
	PCB Costing Workflow.....	1474
	General Process.....	1476
	Modifying and Importing Your PCBA BOM	1477
	Cost Algorithms and Calculations	1478
	How to Cost a PCBA	1479
	PCBA Processes – User Guided.....	1485
	PCBA Processes -- Assembly	1486
	Adhesive Dispense	1486
	Adhesive Staking	1487
	Adhesive Underfill	1488
	Automated Optical Inspection	1489
	Automated Xray Inspection	1490
	Bake In Test	1491
	Bake Out.....	1492
	Batch Wash	1492
	Boundary Scan.....	1493
	Component Prep Automated.....	1493
	Component Prep Manual	1494
	Component Software Load	1494

Conformal Coat	1495
Conformance Certification	1497
Depanelization	1498
Environmental Test	1498
Final Assembly.....	1499
Final Assembly Component Setup	1500
Flying Probe Validation	1500
Functional Test	1501
Hand Wash	1501
Heat Sink Install.....	1502
HiPot Test	1503
InCircuit Test	1504
Inline Wash.....	1504
Ion Chromatography	1505
Jumper Wire Install	1505
Label	1506
Light Up Test	1507
PCB Flip.....	1507
PCB Load.....	1508
PEMS	1509
Potting.....	1509
PTH Auto Insert	1510
PTH Component Setup.....	1511
PTH Hand Install	1511
PTH Hand Solder	1512
Reflow	1512
RF Test.....	1513
Screen Printing	1513
Selective Solder	1515
Shunt Assembly.....	1516
SMT Auto Placement.....	1517
SMT Component Setup	1518
SMT Hand Placement.....	1519
SMT Hand Solder	1519
SMT Visual Inspection	1520
Software Load	1520
Solder Jetting.....	1521
Solder Paste Inspection.....	1522
Stencil	1523
Visual Inspection	1523
Wave Solder	1524
Process Defaults and Thresholds	1525



About This Guide

This section provides information about this Guide, and the other ways in which aPriori supports the aPriori application.

Key topics include:

- Overview
 - Related documents
 - Typographic conventions
 - Feedback and customer support
-

Overview

This Guide contains detailed information about aPriori Cost Models and Process Groups and how to use them to generate costs for parts and assemblies.

Related documents

In addition to this guide, you can find more information about the aPriori application in the following documents:

- *aPriori User Guide* – This guide contains detailed information about the aPriori solution. It is designed as a reference for your everyday work.
- *aPriori System Administration Guide* – This guide contains detailed information about administering the aPriori solution using the System Admin toolset. It is designed as a reference for aPriori system administrators.
- *aPriori VPE Administration Guide* – This guide contains detailed information about using the tools in the virtual production environment (VPE) toolset to maintain the VPEs in your aPriori deployment. It is designed as a reference for VPE administrators.
- *aPriori Cost Model Workbench User Guide* – This guide explains how to use aPriori's Cost Model Work Bench (CMWB) to customize cost models.
- *Release Notes* – This document highlights the changes made in aPriori since the previous release. It also contains last minute information about the release.
- *Installation Guide* – This guide contains detailed information about installing aPriori.
- *System Requirements* – This document provides information on the minimum and recommended client and server requirements to run aPriori, as well as the CAD file formats supported by aPriori.

Typographic conventions

The following conventions are used in this guide to convey additional information.

Style	Description	Example
Code	Code style is used for text that is used literally, appearing exactly as shown. This includes command names, path and file names, and system information.	E:\setup.exe
<i>Italic code</i>	Italic code style is used for names of variables that you must provide. For example, you need to supply a value for <i>your_file</i> in the path name example to the right.	C:\aPriori\ <i>your_file</i>
GUI	GUI style is used to indicate objects in the aPriori interface.	the Document field

GUI Action	GUI Action style is used to indicate objects in the aPriori interface that you click, select, or otherwise act upon.	Click OK .

Note Notes highlight information, provide supplementary information, offer time-saving or easier ways to perform the same task, or explain how to prevent errors or data loss. Be sure to read this information carefully.

Feedback and customer support

We appreciate your comments about this guide. Please contact us with your comments, questions, and requests for technical support.

Website: <http://www.apriori.com/support>

Email: support@apriori.com

1 Introduction

This book provides detailed information on aPriori cost models. It describes the machines, processes, and routings supported by each cost model, as well each cost model's assumptions and limitations. It describes the geometry extraction associated with each cost model. And it provides detailed accounts of each cost model's feasibility requirements, cost formulas, and process setup options, as well as the defaults and thresholds provided by cost model variables.

There is one chapter for each cost model that is provided by a process group (for example, [Assembly Process Group](#), [Bar & Tube Fabrication Process Group](#), or [Casting--Sand Process Group](#)), as well as a few chapters that apply to multiple cost models:

- [Direct and Indirect Overhead](#)
- [Root and Site Cost Model Formulas](#)
- [User Guided Costing](#)

In addition, there is a chapter on each cost model that is provided by a special VPE:

- [User Guided Injection Molding](#)
 - [User Guided Sheet Metal—Progressive Die](#)
 - [User Guided Sheet Metal—Stage Tooling](#)
 - [User Guided Sheet Metal—Turret Press](#)
 - [Wire Harness Process Group](#)
-



2 Direct and Indirect Overhead

This section discusses overhead, which applies to all process groups.

This chapter includes the following topics:

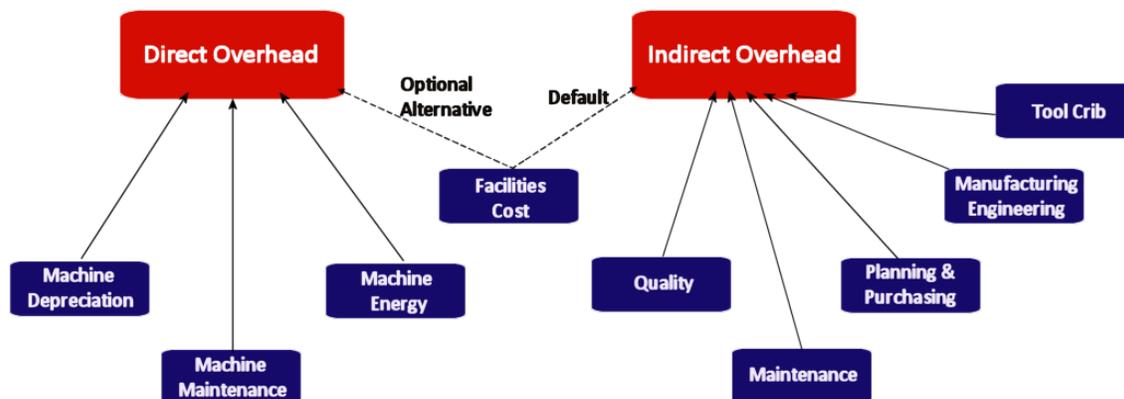
- Overview
 - VPE Variables, Machine Properties, and Overhead Costs
 - Displaying and Overriding Overhead Values
 - Overhead Costs per Part
 - Overhead Rates
 - Annual Direct Overhead
 - Annual Indirect Overhead
 - Overhead Formula Reference
-

Overview

For all process groups, direct and indirect overhead contribute to fully burdened part cost.

Direct overhead accounts for machine depreciation, machine maintenance, and energy to power machines. In addition, users have the option of including facilities cost (rent, insurance, and utilities) in direct overhead (by default, it is included in indirect overhead).

Indirect overhead accounts for support services for quality, maintenance, planning & purchasing, manufacturing engineering (CNC programming and process planning), and tool crib. By default, indirect overhead also includes facility costs (rent, insurance, and utilities), but users have the option of moving facilities cost to direct overhead (see [Annual Direct Overhead](#)).



Direct overhead is included in Total Variable Costs for a part. (Total Variable Costs are shown in the Cost Summary tab, and specified by the CSL formula Piece Cost.)

**Total Variable Costs = Material Cost + Labor Cost +
Direct Overhead Cost per Part + Logistics Cost + Setup Cost per Part + Other
Direct Costs**

The fully burdened part cost is the sum of total variable costs, indirect overhead, and other costs:

**Fully Burdened Cost per Part = Total Variable Costs +
Indirect Overhead Cost per Part + SG&A + Margin + Fixed Costs**

The calculation of per part overhead is introduced in [Overhead Costs per Part](#).

This chapter contains the following subsections:

- VPE Variables, Machine Properties, and Overhead Costs
- Displaying and Overriding Overhead Values
- Overhead Costs per Part
- Overhead Rates
- Annual Direct Overhead
- Annual Indirect Overhead
- Overhead Formula Reference

VPE Variables, Machine Properties, and Overhead Costs

aPiori calculates overhead rates based on two types of fundamental inputs:

- Machine properties, such as **Machine Price**, **Machine Power**, and **Machine Life**, among others
- VPE variables, such as **Prime Lending Rate**, **Purchasing Power Index**, and **Electricity Rate**, among others

You can view machine properties in aPiori Professional in the Machine Selection dialog—right-click a process in the Manufacturing Process pane, and select **Machine Selection...** from the context menu.

You can view and edit VPE variables in the VPE Manager—click the top-level node in the navigation pane.

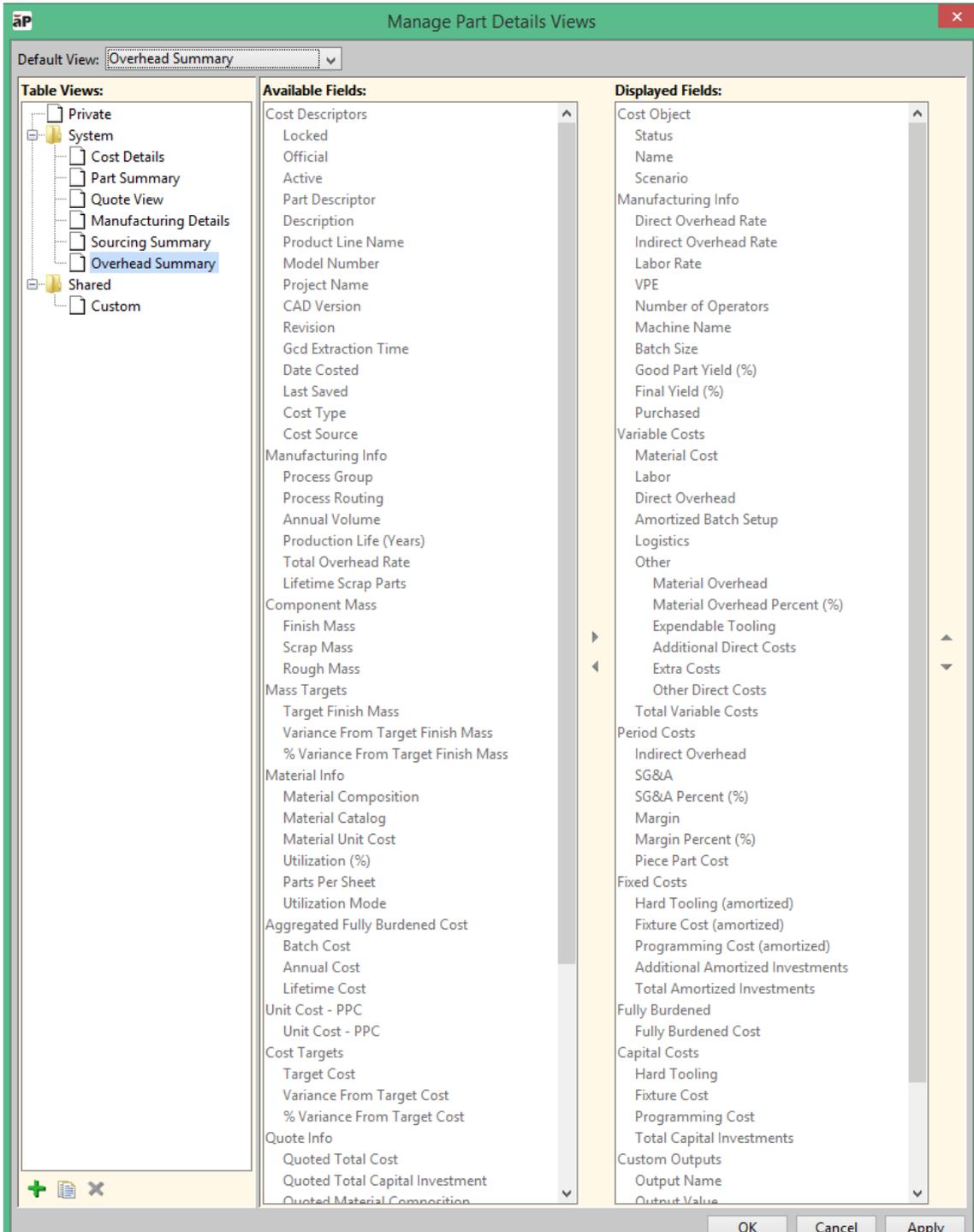
VPE: aPriori USA

Revision	aP2014R2_SP00_F00_(2014-02)
Active	true
Currency Code	USD
Location	United States
VPE Inheritance:	N/A
VPE Material Inheritance:	N/A
VPE Machine Inheritance:	N/A
VPE ToolShop Inheritance:	N/A
Vendor URL	www.apriori.com
Admin	
Batches per Year	12.00
Objective	
Description	
Limitations	
Use Computed Overhead Rate	true
Add Facility Cost to Direct Overhead	false
Use Indirect Overhead Percentage	false
Indirect Overhead Percent (%)	20.00
Imputed Interest Rate (%)	2.35
SG&A Percent (%)	5.00
Purchasing Power Factor	1.00
Non Production Footprint Factor	0.300
Fire Insurance Factor (%)	0.10
Loss Insurance Factor (%)	1.00
Liability Insurance Factor (%)	1.00
Facility Electricity Factor (%)	1.00
Facility Heat and Gas Factor (%)	10.00
Facility Water Factor (%)	1.00
Rent Rate (USD / m ² * yr)	65.12
Electricity Rate (USD / kW * hr)	0.0791
Gas Rate (USD / kW * hr)	0.0129
Quality Support Rate (USD / hr)	32.40

Displaying and Overriding Overhead Values

To view a tree-structured display that shows which formula values contribute directly or indirectly to overhead rates, right click the Direct Overhead Rate or Indirect Overhead Rate value in the Part Details tab and select **Show Formula Dependencies**. Using this display, you can override the values of most overhead-related formulas. See [the Show Formula Dependencies](#) section in the *aPriori User Guide* for more information.

You can display an overhead summary table view by selecting **Select Table View > Overhead Summary** from the Table View menu in in the Part Details tab. See the *aPriori Cost Tables* chapter of the User Guide.



Overhead Costs per Part

For all process groups, aPiori determines direct overhead cost per part with the following formula:

$$\text{Direct Overhead Cost per Part} = \frac{((\text{Labor Cost} * \text{Overhead Multiplier}) + (\text{Direct Overhead Rate} * \text{Cycle Time}))}{\text{Final Yield}}$$

Overhead multiplier is specified by the machine property **Overhead Multiplier**. aPiori determines direct overhead rate in one of two ways:

- Calculated using a group of formulas. aPiori calculates an annual work center budget and translates it into an hourly rate based on the planned number of earned machine hours for the work center. See [Overhead Rates](#) for more information. This method is used if the VPE variable **Use Computed Overhead Rate** is set to **true** (as it is in aPiori starting point VPEs).
- Taken directly from the machine property **Direct Overhead Rate** (adjusted by the factor specified by the cost model variable **overheadRateAdjustmentFactor**). This method is used if the VPE variable **Use Computed Overhead Rate** is set to **false**. (Note that if you have already overridden some overhead-related values before you set this VPE variable to **false**--or change to a VPE that sets it to **false**--**Show Formula Dependencies** may display overhead formulas that are no longer relevant. See the aPiori *User Guide* for more information.)

aPiori determines indirect overhead with one of the following two formulas:

- Based on indirect overhead rate:

$$\text{Indirect Overhead Cost per Part} = \frac{\text{Indirect Overhead Rate} * (\text{Cycle Time} + \text{Amortized Batch Setup})}{\text{Final Yield}}$$

This formula is used if the VPE variable **Use Indirect Overhead Percentage** is set to **false** (as it is in aPiori starting point VPEs). In this case, indirect overhead rate is determined in one of the following two ways:

- Calculated using a group of formulas. aPiori calculates an annual work center indirect overhead budget and translates it into an hourly rate based on the planned number of earned machine hours for the work center. See [Overhead Rates](#) for more information. This method is used if the VPE variable **Use Computed Overhead Rate** is set to **true** (as it is in aPiori starting point VPEs).
- Taken directly from the machine property **Indirect Overhead Rate**. This method is used if the VPE variable **Use Computed Overhead Rate** is set to **false**. (Note that if you have already overridden some overhead-related values before you set this VPE variable to **false**--or change to a VPE that sets it to **false**-- **Show Formula Dependencies** may display overhead formulas that are no longer relevant. See the aPiori *User Guide* for more information.)
- Based on indirect overhead percentage:

$$\text{Indirect Overhead Cost per Part} = \text{Indirect Overhead Percentage} * \text{Piece Cost}$$

This formula is used if the VPE variable **Use Indirect Overhead Percentage** is set to **true**. In this case indirect overhead percentage is taken from the VPE variable **Indirect Overhead Percentage**. (Piece cost includes material, labor, direct overhead, logistics, setup, and expendable tooling costs per part, among other costs.)

Overhead Rates

Computed direct and indirect overhead rates are based on annual overhead costs and annual earned machine hours:

Direct Overhead Rate = Direct Overhead Cost / Annual Earned Machine Hours

Indirect Overhead Rate = Indirect Overhead Cost / Annual Earned Machine Hours

These values are adjusted by the factor specified by the cost model variable **overheadRateAdjustmentFactor**.

Annual earned machine hours is the number of expected machine uptime hours annually:

Annual Earned Machine Hours = Work Center Capacity * Machine Uptime Percent

Work Center Capacity = Hours per Shift * Number of Shifts * Working Days per Year

Hours per shift (specified by the VPE variable **Hours Per Shift**)

Number of shifts (specified by the VPE variable **Number Of Shifts**)

Working days per year (specified by the VPE variable **Working Days Per Year**)

Machine Uptime Percent (specified by the machine property **Machine Uptime Percent**)

Annual overhead cost calculations are described in [Annual Direct Overhead](#) and [Annual Indirect Overhead](#).

Annual Direct Overhead

Annual direct overhead is the sum of costs in five categories:

**Direct Overhead Cost = Annual Depreciation +
Annual Maintenance + Energy to Run Machine + Annual Supplies + Imputed
Interest**

The categories are discussed in the following sections:

- [Annual Depreciation](#)
- [Annual Maintenance](#)
- [Energy to Run Machine](#)
- [Annual Supplies](#)
- [Imputed Interest](#)

By default, facilities cost is *not* included in direct overhead cost, but VPE administrators can override the default and specify that such costs *are* to be counted as part of direct overhead by setting the VPE variable **Add Facility Cost to Direct Overhead** to **true**.

Annual Depreciation

Annual depreciation depends on the cost to buy the machine, the cost to install the machine, and salvage value. aPriori uses linear depreciation, and starting point VPEs typically assume no salvage value. For most machines, aPriori depreciates the machine over 15 years.

Machine costs are obtained from a number of sources, usually the machine manufacturer or a reseller. In some cases aPriori estimates the cost of the machine by considering the cost of similar machines.

The following formulas show how depreciation is calculated:

Annual Depreciation = (Total Cost of Machine - Salvage Value) / Machine Life

Total Cost of Machine = Machine Price + Installation Cost

Machine price (specified by the machine property **Machine Price**)

Installation Cost = Machine Price * Installation Cost Percent

Machine price (specified by the machine property **Machine Price**)

Installation cost percent (specified by the machine property **Installation Cost Percent**)

Salvage Value = Machine Price * Salvage Value Percent

Machine price (specified by the machine property **Machine Price**)

Salvage value percent (specified by the machine property **Salvage Value Percent**)

Machine Life (specified by the machine property **Machine Life**)

Annual Maintenance

Annual maintenance costs are specified as a percentage of machine price, adjusted by a factor that accounts for purchasing power:

Annual Maintenance = Machine Price * Annual Maintenance Percent * Purchasing Power

Machine price (specified by the machine property **Machine Price**)

Annual maintenance percent (specified by the machine property **Annual Maintenance Percent**)

Purchasing power (specified by the VPE variable **Purchasing Power Index**)

Energy to Run Machine

Energy costs depend on machine power and gas or electricity rates, together with annual machine uptime.

Machine Power is typically taken from the manufacturer's specifications. In some cases aPiori estimates the power by analyzing the energy usage of similar machines.

Energy to Run Machine = Annual Energy Usage * Electricity or Gas Rate

Annual Energy Usage = Power * Annual Earned Machine Hours

Power (specified by the machine property **Machine Power**)

Annual Earned Machine Hours = Work Center Capacity * Machine Uptime Percent

Work Center Capacity = Hours per Shift * Number of Shifts * Working Days per Year

Hours per shift (specified by the VPE variable **Hours Per Shift**)

Number of shifts (specified by the VPE variable **Number Of Shifts**)

Working days per year (specified by the VPE variable **Working Days Per Year**)

Machine Uptime Percent (specified by the machine property **Machine Uptime Percent**)

Electricity or gas rate (depending on the machine in use—specified by the VPE variable **Electricity Rate** or **Gas Rate**)

Annual Supplies

aPiori estimates annual supply costs by considering the unique needs of each work center. In addition to general supplies, the estimates account for the need for supplemental equipment to support the work center (such as forklifts, conveyors, and so forth).

Annual supply costs are specified by the machine property **Annual Supplies**.

Imputed Interest

Imputed interest covers investment interest lost due to expenditures for the purchase of the machine. It is the average value of the machine over time, which is assumed to be midway between the initial value and the salvage value:

Imputed Interest = ((Total Cost Of Machine + Salvage Value) / 2) * Imputed Interest Rate

Total Cost of Machine = Machine Price + Installation Cost
 Machine price (specified by the machine property **Machine Price**)
 Installation Cost = Machine Price * Installation Cost Percent
 Machine price (specified by the machine property **Machine Price**)
 Installation cost percent (specified by the machine property **Installation Cost Percent**)

Salvage Value = Machine Price * Salvage Value Percent
 Machine price (specified by the machine property **Machine Price**)
 Salvage value percent (specified by the machine property **Salvage Value Percent**)

Imputed interest rate (specified by the VPE variable **Imputed Interest Rate**; 0 in aPriori starting point VPEs)

Annual Indirect Overhead

Annual indirect overhead costs fall into two categories:

Indirect Overhead Cost = Support Services Cost + Facilities Cost

These categories are discussed in the following sections:

- [Facilities Cost](#)
- [Support Services Cost](#)

Facilities cost is included in indirect overhead cost by default, but VPE administrators can override the default and specify that such costs are to be counted as part of direct overhead by setting the VPE variable **Add Facility Cost to Direct Overhead** to **true**.

Facilities Cost

The Facility budget accounts for the annual costs associated the factory as a whole, including rent, insurance and utility costs (excluding the costs to run the machines).

All these costs depend on work center footprint, which includes the machine footprint plus extra area around the machine (for example for safety, gas lines, and so forth). Rent depends on work center footprint increased by a non-production-area factor, in order to account for non-production space such as hallways and front offices.

Facilities cost is calculated with the following formulas:

Facilities Cost = Annual Rent + Insurance + Utilities

Annual Rent = Work Center Footprint * (1 + Nonproduction Footprint Factor) * Annual Cost Per Square Foot
 Work Center Footprint = Machine Length * Machine Width * Allowance Factor
 Machine length (specified by the machine property **Machine Length**)
 Machine width (specified by the machine property **Machine Width**)
 Allowance factor (specified by the machine property **Allowance Factor For Machine Footprint**)

Insurance = Annual Rent * (Fire Factor + Loss Factor + Liability Factor)
 Annual Rent = Work Center Footprint * (1 + Nonproduction Footprint Factor) * Annual Cost Per Square Foot
 Work Center Footprint = Machine Length * Machine Width * Allowance Factor
 Machine length (specified by the machine property **Machine Length**)
 Machine width (specified by the machine property **Machine Width**)
 Allowance factor (specified by the machine property **Allowance Factor For Machine Footprint**)

Fire Factor (specified by the VPE variable **Fire Insurance Factor**; 0.001 in aPriori starting point VPEs)
 Loss Factor (specified by the VPE variable **Loss Insurance Factor**; 0.1 in aPriori starting point VPEs)
 Liability Factor (specified by the VPE variable **Liability Insurance Factor**; 0.1 in aPriori starting point VPEs)

Utilities = Annual Rent * (Electric Factor + Heat/Gas Factor + Water Factor)
 Annual Rent = Work Center Footprint * (1 + Nonproduction Footprint Factor) * Annual Cost Per Square Foot
 Work Center Footprint = Machine Length * Machine Width * Allowance Factor
 Machine length (specified by the machine property **Machine Length**)
 Machine width (specified by the machine property **Machine Width**)
 Allowance factor (specified by the machine property **Allowance Factor For Machine Footprint**)
 Electric Factor (specified by the VPE variable **Facility Electricity Factor**; 0.01 in aPriori starting point VPEs)
 Heat/Gas Factor (specified by the VPE variable **Facility Heat and Gas Factor**; 0.1 in aPriori starting point VPEs)
 Water Factor (specified by the VPE variable **Facility Water Factor**; 0.01 in aPriori starting point VPEs)

Support Services Cost

Support staff is modeled as a fixed overhead. aPriori estimates the budget for the support group based on the planned capacity for the factory. Support services are the fully burdened salaries and expenses for the following groups:

- Quality
- Maintenance
- Planning & Purchasing
- Engineering
- Tool Crib

Support Services Cost = Quality Support Cost + Maintenance Support Cost + Purchasing Support Cost + Engineering Support Cost + Tool Crib Support Cost

Quality Support Cost = Quality Support Hourly Rate * Quality Support Allocation * Work Center Capacity
 Quality support hourly rate (specified by the VPE variable **Quality Support Hourly Rate**)
 Quality support allocation (specified by the VPE variable **Quality Support Allocation**)
 Work Center Capacity = Hours per Shift * Number of Shifts * Working Days per Year
 Hours per shift (specified by the VPE variable **Hours Per Shift**)
 Number of shifts (specified by the VPE variable **Number Of Shifts**)
 Working days per year (specified by the VPE variable **Working Days Per Year**)

Maintenance Support Cost = Maintenance Support Hourly Rate * Support Allocation * Work Center Footprint * (1 + Nonproduction Footprint Factor) * Annual Earned Machine Hours
 Maintenance support hourly rate (specified by the VPE variable **Maintenance Support Hourly Rate**)
 Support allocation (reciprocal of the VPE variable **Maintenance Worker Coverage**)
 Work Center Footprint = Machine Length * Machine Width * Allowance Factor
 Machine length (specified by the machine property **Machine Length**)
 Machine width (specified by the machine property **Machine Width**)
 Allowance factor (specified by the machine property **Allowance Factor For Machine Footprint**)
 Nonproduction footprint factor (specified by the VPE variable **Non Production Footprint Factor**; 0.3 in aPriori starting point VPEs)
 Annual Earned Machine Hours = Work Center Capacity * Machine Uptime Percent
 Work Center Capacity = Hours per Shift * Number of Shifts * Working Days per Year
 Hours per shift (specified by the VPE variable **Hours Per Shift**)
 Number of shifts (specified by the VPE variable **Number Of Shifts**)
 Working days per year (specified by the VPE variable **Working Days Per Year**)
 Machine Uptime Percent (specified by the machine property **Machine Uptime Percent**)

Purchasing Support Cost = Purchasing Support Hourly Rate * Purchasing Support Allocation * Work Center Capacity
 Purchasing support hourly rate (specified by the VPE variable **Purchasing Support Hourly Rate**)
 Purchasing support allocation (specified by the VPE variable **Purchasing Support Allocation**)
 Work Center Capacity = Hours per Shift * Number of Shifts * Working Days per Year
 Hours per shift (specified by the VPE variable **Hours Per Shift**)
 Number of shifts (specified by the VPE variable **Number Of Shifts**)
 Working days per year (specified by the VPE variable **Working Days Per Year**)

Engineering Support Cost = Engineering Support Hourly Rate * Engineering Support Allocation * Work Center Capacity
Engineering support hourly rate (specified by the VPE variable **Engineering Support Hourly Rate**)
Engineering support allocation (specified by the VPE variable **Engineering Support Allocation**)
Work Center Capacity = Hours per Shift * Number of Shifts * Working Days per Year
Hours per shift (specified by the VPE variable **Hours Per Shift**)
Number of shifts (specified by the VPE variable **Number Of Shifts**)
Working days per year (specified by the VPE variable **Working Days Per Year**)

Tool Crib Support Cost = Tool Crib Support Hourly Rate * Tool Crib Support Allocation * Work Center Capacity
Tool Crib support hourly rate (specified by the VPE variable **Tool Crib Support Hourly Rate**)
Tool Crib support allocation (specified by the VPE variable **Tool Crib Support Allocation**)
Work Center Capacity = Hours per Shift * Number of Shifts * Working Days per Year
Hours per shift (specified by the VPE variable **Hours Per Shift**)
Number of shifts (specified by the VPE variable **Number Of Shifts**)
Working days per year (specified by the VPE variable **Working Days Per Year**)

Overhead Formula Reference

Below are the formulas (listed alphabetically by formula name) that aPirori uses for all process groups to calculate direct and indirect overhead rates. For overhead cost per part see [Overhead Costs per Part](#). Note that the user can override formula values—see [Displaying and Overriding Overhead Values](#).

This section covers the following formulas:

- [Annual Depreciation](#)
- [Annual Earned Machine Hours](#)
- [Annual Energy Usage](#)
- [Annual Maintenance](#)
- [Annual Rent](#)
- [Direct Overhead Cost](#)
- [Direct Overhead Rate](#)
- [Energy to Run Machine](#)
- [Engineering Support Cost](#)
- [Facilities Cost](#)
- [Imputed Interest](#)
- [Indirect Overhead Cost](#)
- [Installation Cost](#)
- [Insurance](#)
- [Maintenance Support Cost](#)
- [Purchasing Support Cost](#)
- [Quality Support Cost](#)
- [Salvage Value](#)
- [Support Services Cost](#)
- [Tool Crib Services Cost](#)
- [Total Cost of Machine](#)
- [Utilities](#)
- [Work Center Capacity](#)
- [Work Center Footprint](#)

Annual Depreciation = (Total Cost of Machine - Salvage Value) / Machine Life

Annual depreciation depends on the following:

- Total cost of machine (see [formula](#))
- Salvage value (see [formula](#))
- Machine life (specified by the machine property **Machine Life**).

See also [Annual Depreciation](#) and [Annual Direct Overhead](#).

Annual Earned Machine Hours = Work Center Capacity * Machine Uptime Percent

Annual earned machine hours is the product of the following:

- Work center capacity (see [formula](#))
- Machine uptime percent (specified by the machine property **Machine Uptime Percent**)

See also [Overhead Rates](#), [Energy to Run Machine](#), and [Support Services Cost](#).

Annual Energy Usage = Power * Annual Earned Machine Hours

Annual energy usage is the product of the following:

- Power (specified by the machine property **Machine Power**)
- Annual earned machine hours (see [formula](#))

This value contributes to [Energy to Run Machine](#) and [Annual Direct Overhead](#).

Annual Maintenance = Machine Price * Annual Maintenance Percent * Purchasing Power

Annual maintenance is the product of the following:

- Machine price (specified by the machine property **Machine Price**)
- Annual maintenance percent (specified by the machine property **Annual Maintenance Percent**)
- Purchasing power (specified by the VPE variable **Purchasing Power Index**)

See also [Annual Maintenance](#) and [Annual Direct Overhead](#).

Annual Rent = Work Center Footprint * (1 + Nonproduction Footprint Factor) * Annual Cost Per Square Foot

Annual rent depends on the following:

- Work center footprint (see [formula](#))
- Nonproduction footprint factor, which accounts for non-production space such as hallways and front offices (specified by the VPE variable **Non Production Footprint Factor**; 0.3 in aPriori starting point VPEs)
- Annual cost per square foot (specified by the VPE variable **Rent Rate**)

This value contributes to [Facilities Cost](#) and [Annual Indirect Overhead](#).

Direct Overhead Cost = Annual Depreciation + Annual Maintenance + Energy to Run Machine + Annual Supplies + Imputed Interest

Direct overhead cost is the sum of the following:

- Annual depreciation (see [formula](#))
- Annual maintenance (see [formula](#))
- Energy to run machine (see [formula](#))
- Annual supplies (specified by the machine property **Annual Supplies**)

- Imputed interest (see [formula](#))

By default, facilities cost (see [formula](#)) is *not* included in direct overhead cost, but VPE administrators can override the default and specify that such costs *are* to be counted as part of direct overhead—see [Facilities Cost](#).

See also [Annual Direct Overhead](#).

Direct Overhead Rate = Direct Overhead Cost / Annual Earned Machine Hours

Direct overhead rate depends on the following:

- Direct overhead cost (see [formula](#))
- Annual earned machine hours (see [formula](#))

If the VPE variable `Use Computed Overhead Rate` is `false`, this formula is not used; instead, direct overhead rate is taken directly from the machine property `Direct Overhead Rate`.

See also [Overhead Rates](#).

Energy to Run Machine = Annual Energy Usage * Electricity Or Gas Rate

Energy to run machine is the product of the following:

- Annual energy usage (see [formula](#))
- Electricity or gas rate (depending on the machine in use—specified by the VPE variable `Electricity Rate Or Gas Rate`)

See also [Energy to Run Machine](#) and [Annual Direct Overhead](#).

Engineering Support Cost = Engineering Support Hourly Rate * Engineering Support Allocation * Work Center Capacity

Engineering support cost is the product of the following:

- Engineering support hourly rate (specified by the VPE variable `Engineering Support Hourly Rate`)
- Engineering support allocation (specified by the VPE variable `Engineering Support Allocation`)
- Work center capacity (see [formula](#))

This value contributes to [Support Services Cost](#) and [Annual Indirect Overhead](#).

Facilities Cost = Annual Rent + Insurance + Utilities

By default, facilities cost is included in indirect overhead rather than direct overhead. VPE administrators can override the default by setting the VPE variable `Add Facility Cost to Direct Overhead` to `true`. Facilities cost is the sum of the following:

- Annual Rent (see [formula](#))
- Insurance (see [formula](#))
- Utilities (see [formula](#))

See also [Facilities Cost](#) and [Annual Indirect Overhead](#).

Imputed Interest = ((Total Cost Of Machine + Salvage Value) / 2) * Imputed Interest Rate

Imputed interest is the average value of the machine over time, which is assumed to be midway between the initial value and the salvage value. It depends on the following:

- Total cost of machine (see [formula](#))

- Salvage value (see [formula](#))
- Imputed interest rate (specified by the VPE variable `Imputed Interest Rate`; 0 in aPriori starting point VPEs)

See also [Imputed Interest](#) and [Annual Direct Overhead](#).

Indirect Overhead Cost = Support Services Cost + Indirect Overhead Facilities Cost

Indirect overhead cost is the product of the following:

- Support services cost (see [formula](#))
- Indirect overhead facilities cost (see [formula](#))

See also [Annual Indirect Overhead](#).

Indirect Overhead Rate = Indirect Overhead Cost / Annual Earned Machine Hours

Indirect overhead rate depends on the following:

- Indirect overhead cost (see [formula](#))
- Annual earned machine hours (see [formula](#))

If the VPE variable `Use Computed Overhead Rate` is `false`, this formula is not used; instead, indirect overhead rate is taken directly from the machine property `Workcenter Indirect Overhead Rate`.

See also [Overhead Rates](#).

Installation Cost = Machine Price * Installation Cost Percent

Installation cost is the product of the following:

- Machine price (specified by the machine property `Machine Price`)
- Installation cost percent (specified by the machine property `Installation Cost Percent`)

This value contributes to [Annual Depreciation](#), [Imputed Interest](#), and [Annual Direct Overhead](#).

Insurance = Annual Rent * (Fire Factor + Loss Factor + Liability Factor)

Insurance cost depends on the following:

- Annual Rent (see [formula](#))
- Fire Factor (specified by the VPE variable `Fire Insurance Factor`; 0.001 in aPriori starting point VPEs)
- Loss Factor (specified by the VPE variable `Loss Insurance Factor`; 0.1 in aPriori starting point VPEs)
- Liability Factor (specified by the VPE variable `Liability Insurance Factor`; 0.1 in aPriori starting point VPEs)

This value contributes to [Facilities Cost](#) and [Annual Indirect Overhead](#).

Maintenance Support Cost = Maintenance Support Hourly Rate * Support Allocation * Work Center Footprint * (1 + Nonproduction Footprint Factor) * Annual Earned Machine Hours

Maintenance support cost depends on the following:

- Maintenance support hourly rate (specified by the VPE variable `Maintenance Support Hourly Rate`)

- Support allocation (reciprocal of the VPE variable **Maintenance Worker Coverage**)
- Work center footprint (see [formula](#))
- Nonproduction footprint factor, which accounts for non-production space such as hallways and front offices (specified by the VPE variable **Non Production Footprint Factor**; 0.3 in aPiori starting point VPEs)
- Annual earned machine hours (see [formula](#))

This value contributes to [Support Services Cost](#) and [Annual Indirect Overhead](#).

Purchasing Support Cost = Purchasing Support Hourly Rate * Purchasing Support Allocation * Work Center Capacity

Purchasing support cost is the product of the following:

- Purchasing support hourly rate (specified by the VPE variable **Purchasing Support Hourly Rate**)
- Purchasing support allocation (specified by the VPE variable **Purchasing Support Allocation**)
- Work center capacity (see [formula](#))

This value contributes to [Support Services Cost](#) and [Annual Indirect Overhead](#).

Quality Support Cost = Quality Support Hourly Rate * Quality Support Allocation * Work Center Capacity

Quality support cost is the product of the following:

- Quality support hourly rate (specified by the VPE variable **Quality Support Hourly Rate**)
- Quality support allocation (specified by the VPE variable **Quality Support Allocation**)
- Work center capacity (see [formula](#))

This value contributes to [Support Services Cost](#) and [Annual Indirect Overhead](#).

Salvage Value = Machine Price * Salvage Value Percent

Salvage value is the product of the following:

- Machine price (specified by the machine property **Machine Price**)
- Salvage value percent (specified by the machine property **Salvage Value Percent**)

This value contributes to [Annual Depreciation](#) and [Annual Direct Overhead](#).

Support Services Cost = Quality Support Cost + Maintenance Support Cost + Purchasing Support Cost + Engineering Support Cost + Tool Crib Support Cost

Support services cost is the sum of the following:

- Quality support cost (see [formula](#))
- Maintenance support cost (see [formula](#))
- Purchasing support cost (see [formula](#))
- Engineering support cost (see [formula](#))
- Tool crib support cost (see [formula](#))

This value contributes to [Annual Indirect Overhead](#).

Tool Crib Support Cost = Tool Crib Support Hourly Rate * Tool Crib Support Allocation * Work Center Capacity

Tool crib support cost is the product of the following:

- Tool crib support hourly rate (specified by the VPE variable **Tool Crib Support Hourly Rate**)
- Tool crib support allocation (specified by the VPE variable **Tool Crib Support Allocation**)
- Work center capacity (see [formula](#))

This value contributes to [Support Services Cost](#) and [Annual Indirect Overhead](#).

Total Cost of Machine = Machine Price + Installation Cost

Total cost of machine is the sum of the following:

- Machine price (specified by the machine property **Machine Price**)
- Installation cost (see [formula](#))

This value contributes to [Annual Depreciation](#), [Imputed Interest](#), and [Annual Direct Overhead](#).

Utilities = Annual Rent * (Electric Factor + Heat/Gas Factor + Water Factor)

Utilities cost depends on the following:

- Annual Rent (see [formula](#))
- Electric Factor (specified by the VPE variable **Facility Electricity Factor**; 0.01 in aPriori starting point VPEs)
- Heat/Gas Factor (specified by the VPE variable **Facility Heat and Gas Factor**; 0.1 in aPriori starting point VPEs)
- Water Factor (specified by the VPE variable **Facility Water Factor**; 0.01 in aPriori starting point VPEs)

This value contributes to [Facilities Cost](#) and [Annual Indirect Overhead](#).

Work Center Capacity = Hours Per Shift * Number Of Shifts * Working Days Per Year

Work center capacity is the product of the following:

- Hours per shift (specified by the VPE variable **Hours Per Shift**)
- Number of shifts (specified by the VPE variable **Number Of Shifts**)
- Working days per year (specified by the VPE variable **Working Days Per Year**)

This value contributes to [Annual Earned Machine Hours](#) and [Support Services Cost](#).

Work Center Footprint = Machine Length * Machine Width * Allowance Factor

Work center footprint includes the machine footprint plus extra area around the machine, for example, for safety, gas lines, and so forth. It is the product of the following:

- Machine length (specified by the machine property **Machine Length**)
- Machine width (specified by the machine property **Machine Width**)
- Allowance factor (specified by the machine property **Allowance Factor For Machine Footprint**)

This value contributes to [Facilities Cost](#) and [Annual Indirect Overhead](#).

3 Root and Site Cost Model Formulas

This chapter describes the formulas in the Root and Site cost models. These formulas are evaluated at each node in the current process-level routing that has a taxonomy module, including at the routing's top-level node, after all the other taxonomy modules have been evaluated. The formulas are contained in two modules: the rollup module and the global taxonomy module. These modules serve three purposes:

- Define highest-level cost categories, such as fully burdened cost, piece cost, and total amortized investment.
- Provide default formulas for the quantities that are required in order to calculate these high-level costs (fully burdened cost, piece cost, amortized investment, and so forth).
- Aggregate the results from the current node's child nodes in the current routing.

The site cost model is initially the same as the root cost model, but it can be customized by users of the Cost Model Workbench.

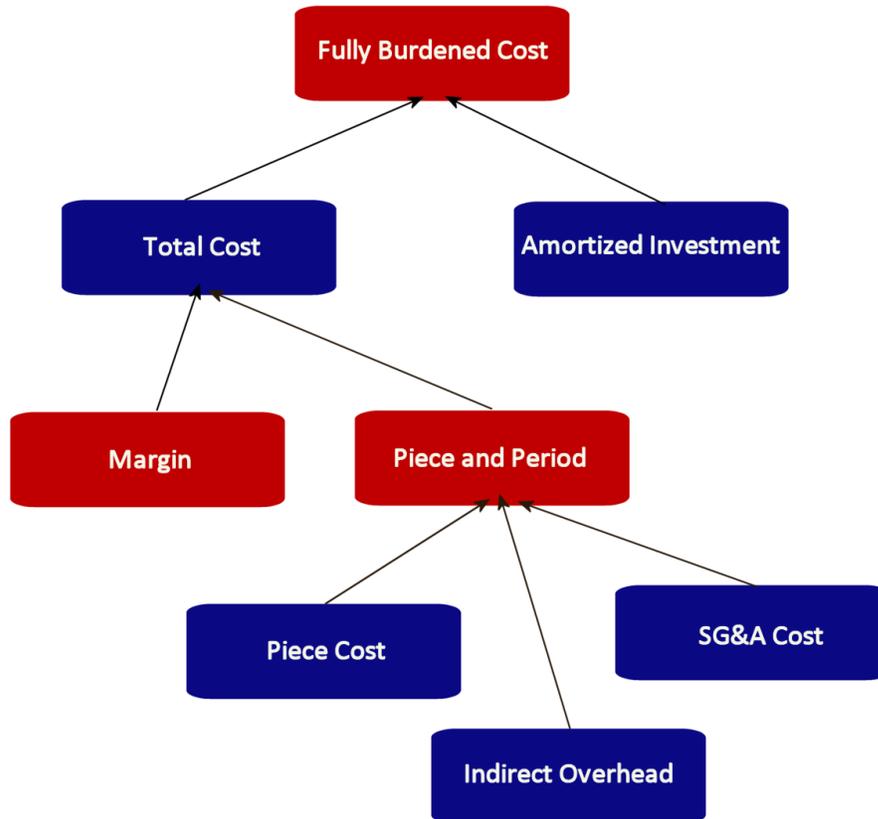
See also the User Guide chapter *aPriori Cost Tables* for information on the various cost categories.

This chapter includes the following topics:

- Fully Burdened Cost
 - Piece Cost
 - Other Direct Costs
 - Amortized Investment
-

Fully Burdened Cost

Fully burdened cost is defined by the formulas in this section.



Fully Burdened Cost per Part = Total Cost + Amortized Investment

Fully burdened cost is defined in the rollup module. It is the sum of the following per part costs:

- Total cost (also known as “Piece Part Cost”. See the formula below)
- Amortized investment (see [Amortized Investment](#))

Total Cost = Margin + Piece and Period

Total cost is defined in the Site cost model rollup. Total cost is the sum of the following per part costs:

- Margin: by default it is the product of piece and period and the value of the cost model variable `marginRate`.
- Piece and period (see the formula below)

Piece and Period = Piece Cost + Indirect Overhead Cost + SG&A

Piece and period is defined in the Site cost model global taxonomy module. It is the sum of the following per part costs:

- Piece cost (see [Piece Cost](#))
- Indirect overhead cost (also known as “period overhead”--see [Overhead Costs per Part](#))
- SG&A: this is the per part cost for SG&A (sales, general, and administration). By default this is the product of the piece cost and the value of the cost model variable `sgaPercent`.

Piece Cost

**Piece Cost = Material Cost + Labor Cost +
Direct Overhead Cost + Logistics Cost + Setup Cost + Other Direct Costs**

Piece cost is defined in the Site cost model global taxonomy module. Piece cost is the sum of the following per part costs:

- Material cost (result of aggregating material costs from the current node's children)
- Labor cost (result of aggregating labor costs from the current node's children)
- Direct overhead cost: see [Overhead Costs per Part](#)
- Logistics cost (result of aggregating logistics costs from the current node's children)
- Setup cost: also known as “amortized batch setup”, this is the result of aggregating setup costs from the current node's children.
- Other direct costs (see [Other Direct Costs](#))

Other Direct Costs

**Other Direct Costs = Expendable Tooling Cost +
Additional Direct Costs + Extra Costs + Material Overhead Cost**

Other direct costs is defined in the global taxonomy module. It is the sum of the following per part costs:

- Expendable tooling costs (result of aggregating expendable tooling costs from the current node's children)
- Additional direct costs (result of aggregating additional direct costs from the current node's children)
- Extra costs (result of aggregating extra costs from the current node's children)
- Material overhead costs: this is the per part cost for material overhead (overhead costs associated with purchasing and storing material, as well as moving materials to the workcenter). By default this is the product of material cost and the value of the VPE variable `materialOverheadPercent`.

Amortized Investment

**Amortized Investment = Tooling Cost +
Fixture Cost + Programming Cost + Additional Amortized Investment**

Amortized investment is defined in the Site cost model rollup module. It is the sum of the following per part costs:

- Tooling cost
- Fixture cost
- Programming cost
- Additional amortized investment

These per part costs are derived by dividing the corresponding total costs by the current scenario's total production volume. The total costs are the result of aggregating the total from the current node's child nodes in the current routing.

Total production volume is the product of the annual volume and number of production years, specified in the Production Scenario screen of the Cost Guide.



4 Assembly Process Group

This section describes the costing details and inputs that are available for the Assembly process group. With this group, aPriori estimates times and costs for assembling components by using welding and/or mechanical assembly. Routings can also include secondary processes if you have licensed them.

This chapter includes the following topics:

- Cost Model Overview
 - Feasibility and Routing
 - Cost Algorithms and Calculations
 - User Inputs
 - Process Defaults and Thresholds
 - Assembly Welds
 - Assembly Views
-

Cost Model Overview

This overview section summarizes assumptions and limitations of the following aspects of the model:

- General Process
- Part Geometry
- Materials
- Machines
- Tooling

General Process

The following sections list Assembly processes, describe some important assumptions of the Assembly cost model, and discuss several ways in which Assembly processes differ from the processes in other process groups.

- Supported Processes
- Assembly Cost Tables
- Labor Time and Cycle Time
- Labor Time, Cycle Time, and Number of Operators
- Overhead
- Cycle Time Overrides and Adjustments
- Task Parallelism and Robotic Welding

Supported Processes

Assembly process group routings support the following main processes:

- Pick and Place: includes picking each subcomponent from a bin and loading into the assembly or fixture. It also includes clamping the part in the fixture and/or reorienting the part if necessary.
- Lock Bolt: uses a bolt-type fastener which is permanently installed and cannot be removed, providing a vibration resistant and maintenance free joint. You must manually assign the Lock Bolt operation (Lock Bolt Install) to one member of each pair of subcomponents to be joined in this fashion.
- Threaded Insert: installs inserts into threaded holes in order to make screws and bolts more secure and resistant to vibrations and impacts. You must manually assign the Threaded Insert operation to one member of each pair of subcomponents to be joined with the help of such an insert. (You must separately assign a Screw Tighten operation from the Mechanical Assembly process.)
- Rivet: either rivets all holes within a specified size range, or rivets a specified number of holes.

- **Mechanical Assembly:** includes assembly operations that are assumed to be performed by hand on specified components. These operations include Nut Insert, Rivet, Press Fit, and Tab Bend, among others. You must manually assign an operation to each subcomponent that requires it. In a case where two subcomponents are held together with a fastener, a fastening operation only needs to be applied to one of the subcomponents.
- **Adhesive Bonding:** uses a high-strength bond to join components that are made of various materials. You must manually include the Adhesive Bonding process in your routing; adhesive bonding is then assumed to be applied to a certain percentage of the assembly's total surface area (10% by default, in starting point VPEs).
- **Sealing:** there are three sealing processes, which are used to prevent gas or moisture from getting between components:
 - Cap Sealing: applied around fasteners or rivets.
 - Fay Sealing: used to prevent galvanic (dissimilar metal) corrosion.
 - Fillet Sealing: applied to relatively long, thin regions.
- **Welding:** there are eight welding processes:
 - Manual MIG Welding
 - Manual TIG Welding
 - Manual Spot Welding
 - Robotic MIG Welding
 - Robotic TIG Welding
 - Robotic Spot Welding
 - Electron Beam Welding
 - Laser Welding

Each welding process has a single operation, which the cost model applies to each appropriate Weld GCD—see [Welding Operation Feasibility](#) for more information.

Welding is optionally preceded by the Weld Prep process (Bevel Cutting, Grinding, and/or Wire Brushing operations) and optionally followed by Weld Clean Up (Grinding operations). You must manually assign the appropriate prep and cleanup operations to the appropriate Weld GCDs.

Optional secondary processes include Machining, Surface Treatment, Heat Treatment, and Packaging, if you have licensed these modules.

Assembly Cost Tables

The cost tables for assemblies include the following:

- Assembly Details
- Assembly Tracker
- Cost Summary

See [Assembly Views](#) for more information. See also the Cost Tables chapter of the aPriori User Guide.

The Cost Summary table for assemblies has several notable features:

- All costs listed at and above **Assembly Process Fully Burdened Cost** including only costs for assembly processes, and exclude costs for manufacturing the subcomponents.
- Subcomponent process costs are listed at **Fully Burdened Cost of Subcomponents**.
- Material Cost is always 0.

Assembly Details		Assembly Tracker	Cost Summary	Current (USD)
Variable Costs				
	Material Cost	Material cost is always 0		0.00
▲	Labor			1.31
▲	Direct Overhead			0.04
	Amortized Batch Setup			0.30
	Logistics			0.00
▲	Other Direct Costs			0.01
▲	Total Variable Costs	All these costs include only Assembly process costs, not costs to manufacture subcomponents.		1.67
Period Costs				
▲	Indirect Overhead			0.48
▲	SG&A			0.08
	Margin			0.00
▲	Piece Part Cost			2.23
Fixed Costs				
▲	Total Amortized Investments			0.00
▲	Assembly Process Fully Burdened Cost			2.23
	Fully Burdened Cost of Subcomponents			1.04
▲	Fully Burdened Cost	Subcomponent costs come in here		3.27
Capital Costs				
▲	Total Capital Investments			0.00

Labor Time and Cycle Time

The assembly cost model derives costs largely from data about standard times associated with basic assembly tasks (such as tightening a screw, or bending a tab). For each task, this is the time it takes one operator to perform that task. The model calculates labor time per part based on these values. In contrast to other process groups, which derive labor time from cycle time, Assembly processes derive cycle time from labor time.

Labor Time, Cycle Time, and Number of Operators

For processes from other groups, increasing the number of operators typically increases labor time and labor cost per part, and does not affect cycle time per part. For Assembly

processes (except robotic processes), in contrast, increasing the number of operators decreases cycle time and does not affect labor time or labor cost. The Assembly cost model assumes the use of an assembly line that can be sped up or slowed down through the addition or removal of operators.

In general, with the exception of robotic processes, cycle time is assumed to be inversely proportional to the number of operators, and labor time is assumed to be independent of the number of operators—with certain exceptions related to robotic processes.

Overhead

As with other process groups, indirect overhead for Assembly processes depends on cycle time:

Indirect Overhead Cost per Part =
Indirect Overhead Rate * (Cycle Time + Amortized Batch Setup) / Final Yield

But unlike other process groups, direct overhead for Assembly processes is independent of cycle time:

Direct Overhead Cost per Part =
((Labor Cost * Overhead Multiplier) + (Direct Overhead Rate * Labor Time)) / Final Yield

Cycle Time Overrides and Adjustments

Because cycle time does not affect direct overhead, and because cycle time is derived from labor time (and not vice versa), cycle time affects costs only through its effect on indirect overhead. This means that overriding cycle time (or adjusting it with the cost model variable **cycleTimeAdjustmentFactor**) doesn't affect labor time or labor cost. You should override or adjust cycle time only to affect indirect overhead, for example, to account for the cost of extra buffer space required by an unbalanced push assembly line.

Task Parallelism and Robotic Welding

For routings that include Robotic MIG Welding or Robotic TIG Welding, the cost model assumes that at least some of the Robotic Welding operators perform manual tack welding and pick and place tasks, in addition to tending to one or more robotic welding machines (one, by default). This can sometimes reduce costs compared to routings with Manual Welding, because the operator is assumed do tacking and pick and place on one piece during the time that the robot is welding another piece.

The number of operators for the Pick and Place process (specified by a PSO or machine property) indicates the total number of operators performing pick and place tasks, including the Robotic MIG Welding operators that perform pick and place tasks. By default, for routings with Robotic MIG Welding, the cost model assumes that there are no dedicated pick and place operators, and that all pick and place tasks are performed by one Robotic MIG Welding operator.

Part Geometry

Assemblies have two special types of GCDs:

- Subcomponents (visible when you expand **Subcomponents** in the Geometric Cost Drivers pane): the current assembly is composed of parts and possibly other assemblies. Each such part or assembly corresponds to a subcomponent GCD. For more information see *Working with assembly components* in the User Guide chapter Using aPriori Desktop.
- Welds (listed under **Joining** in the Geometric Cost Drivers pane): weld GCDs are either extracted from the CAD model or (for virtual welds) added manually with the Weld tool—see [Assembly Welds](#) for more information.

Note that the **Component** GCD **Component:1** represents the assembly as a whole.

Note also that the Assembly process group does not extract any other types of GCDs, such as holes or bends in subcomponents.

Geometric Cost Drivers								
Show ▼								
Status	Name	Component	Properties				Results	
			Part Number	Mass (kg)	Length (mm)	Width (mm)	Height ...	Time (s)	Status
●	[-] Component	...						
●	[-] Base Properties [1]	ap_bracket_hang...	0.22	70.00	64.00	40.00	20	●
●	[-] Component:1	ap_sheetmtl_dee...	0.85	305.21	119.10	82.00	20	●
●	[-] Subcomponents [4]	fastener_deep_co...	0.00	12.00	12.00	2.00	13	●
●	[-] AP_SHEETMTL_DEEP_COSTING...	weld_support_de...	0.16	157.28	63.64	4.00	17	●
●	[-] AP_BRACKET_HANGER_DEEP_...							
●	[-] WELD_SUPPORT_DEEP_COSTI...							
●	[-] FASTENER_DEEP_COSTING_EL...							
●	[-] Joining							
●	[-] Welds							
●	[-] Virtual Welds [1]							
●	[-] Weld:1							

Materials

The processes in this group do not use any material; material cost is always 0 for all processes. Welding wire is considered to be expendable tooling—see [MIG Welding Expendable Tooling Calculation](#), [TIG Welding Expendable Tooling Calculation](#), and [Spot Welding Expendable Tooling Calculation](#).

Machines

Welding machines in starting point VPEs include the following:

- Miller manual spot welders
- PerformArc robotic spot welders
- ESAB and Deltaweld manual MIG welders
- Pro Robots and ICS Robotics robotic MIG welders
- MINIARC and Maxstar manual TIG welders

- Motoman robotic TIG welders

Each welding process also has a default, virtual machine. The following tables list various properties for MIG welding machines (other machine properties don't vary from MIG welding machine to MIG welding machine):

Manual MIG Welding

Property	Low End	High End
Wire Feed Rate (mm / sec)	148.0	212.0
Wire Diameter (mm)	0.89	1.32
Machine Length (mm)	914.40	966.22
Machine Width (mm)	457.20	661.42
Price (USD)	3400.00	3715.00
Machine Direct Overhead Rate (USD / hr)	1.07	1.09
Machine Indirect Overhead Rate (USD / hr)	8.85	9.05

Robotic MIG Welding

Property	Low End	High End
Wire Feed Rate (mm / sec)	148.0	212.0
Wire Diameter (mm)	0.89	1.60
Machine Length (mm)	6096.00	6096.00
Machine Width (mm)	3048.00	3048.00
Price (USD)	100,000.00	100,000.00
Machine Direct Overhead Rate (USD / hr)	8.95	8.95
Machine Indirect Overhead Rate (USD / hr)	10.64	10.64

Manual TIG Welding

Property	Low End	High End
Wire Feed Rate (mm / sec)	267.0	267.0
Machine Length (mm)	400.00	1111.00
Machine Width (mm)	146.00	610.00
Price (USD)	932.00	17,544.00
Machine Direct Overhead Rate (USD / hr)	1.07	1.07
Machine Indirect Overhead Rate (USD / hr)	12.09	12.09

Robotic TIG Welding

Property	Low End	High End
Wire Feed Rate (mm / sec)	267.0	267.0
Machine Length (mm)	2868.00	6242.00
Machine Width (mm)	2475.00	5615.00
Price (USD)	65,000.00	150,000.00
Machine Direct Overhead Rate (USD / hr)	6.48	6.48
Machine Indirect Overhead Rate (USD / hr)	10.76	10.76

Manual Spot Welding

Property	Low End	High End
Power (kW)	10	34
Price (USD)	605.00	5340.00
Length (mm)	914.40	966.22
Machine Direct Overhead Rate (USD / hr)	0.84	3.12
Machine Indirect Overhead Rate (USD / hr)	8.95	8.99

Robotic Spot Welding

Property	Low End	High End
Power (kW)	10	10
Price (USD)	100,000.00	100,000.00
Length (mm)	6096.00	6096.00
Machine Direct Overhead Rate (USD / hr)	8.95	8.95
Machine Indirect Overhead Rate (USD / hr)	10.64	10.64

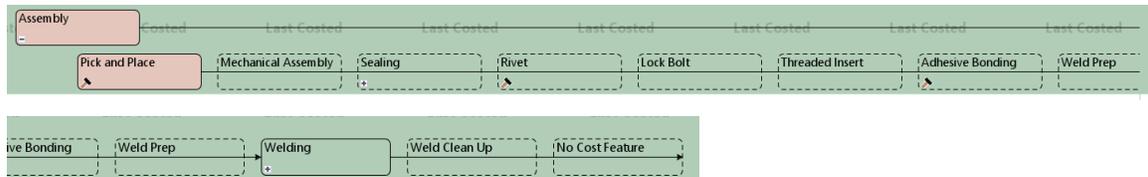
See [Machine Selection](#) for more information.

Tooling

The processes in this group do not use non-expendable tooling. Welding wire is considered to be expendable tooling—see [MIG Welding Expendable Tooling Calculation](#), [TIG Welding Expendable Tooling Calculation](#), and [Spot Welding Expendable Tooling Calculation](#).

Feasibility and Routing

Assembly process group routings consists of Pick and Place followed by Mechanical Assembly, various sealing, fastening, and bonding processes, and/or Welding. Welding is optionally preceded by Weld Prep and optionally followed by Weld Clean Up.



Optional secondary processes include Machining, Surface Treatment, Heat Treatment, and Packaging.

This section contains the following subsections:

- [Adhesive Bonding Routing](#)
- [Lock Bolt Routing](#)
- [Threaded Insert Routing](#)
- [Pick and Place Routing](#)
- [Mechanical Assembly Routing](#)
- [Sealing Routings](#)
- [Rivet Process Routing](#)
- [Welding Routing](#)
- [Welding Operation Feasibility](#)

- Weld Prep Operation Feasibility
- Material Selection
- Machine Selection

Adhesive Bonding Routing

You must manually include the Adhesive Bonding process in your routing; adhesive bonding is then assumed to be applied to a certain percentage of the assembly's total surface area (10% by default, in starting point VPEs).

Lock Bolt Routing

You must manually assign the Lock Bolt operation (Lock Bolt Install) to one member of each pair of subcomponents to be joined using a lock bolt.

Threaded Insert Routing

You must manually assign the Threaded Insert operation to one member of each pair of subcomponents to be joined with the help of a threaded insert. (You must separately assign a Screw Tighten operation from the Mechanical Assembly process.)

Sealing Routings

There are three sealing processes, each of which must be manually included in your routing:

- Cap Sealing: used to seal the contact points of a fastener.
- Fay Sealing: used to seal flat contact areas between two parts.
- Fillet Sealing: used to seal flat contact areas between two parts.

Rivet Process Routing

You must manually include the Rivet process in your process routing. This process accounts for the cost of riveting all the assembly's holes that are within a specified size range, or riveting a specified number of holes. You must cost all subcomponents of the assembly before you include this process. Note that you can also rivet a specified subcomponent with the Rivet operation of the Mechanical Assembly process.

Pick and Place Routing

The Pick and Place process supports the following operations:

- Load: load the part into the assembly fixture or to a mating part already assembled, including bin pick and insertion. This is included in the operation sequence for all the assembly's components.

- Clamp: clamp the part in the fixture in order to prepare it for subsequent operations. This is automatically included in the operation sequence for all the assembly's subcomponents, if the assembly has welds.
- Reorient: turn over or otherwise reorient the assembly. If reorienting is necessary for your assembly, you must manually assign this operation to one or more subcomponents.

Mechanical Assembly Routing

You must manually assign Mechanical Assembly operations (such as Nut Insert, Press Fit, or Rivet) to each subcomponent that requires it. Mechanical Assembly is included in the current routing only if you make at least one such assignment. The Mechanical Assembly process supports the following operations:

- Nut Insert
- Press Fit
- Rivet
- Screw Tighten – Manual
- Screw Tighten – Power
- Snap Fit
- Tab Bend

Note: In a case where two components are held together with a fastener, a fastening operation only needs to be applied to one of the components. In a case where a bolt, nut, and washer that will be used to secure part of the assembly are modeled, the fastening operation only needs to be applied to one of the components.

Welding Routing

Welding processes are included in the current routing only if the current assembly contains welds. In many cases you must manually create virtual welds—see [Assembly Welds](#). There are eight welding processes:

- Manual MIG Welding
- Manual TIG Welding
- Manual Spot Welding
- Robotic MIG Welding
- Robotic TIG Welding
- Robotic Spot Welding
- Electron Beam Welding
- Laser Welding

Each process supports a single welding operation. The characteristics of each weld GCD determine which welds are handled by which process's operation—see [Welding Operation Feasibility](#).

For the following processes, you must manually assign the corresponding welding operation to each weld that requires it:

- Manual TIG Welding
- Robotic TIG Welding
- Laser Welding
- Electron Beam

In the Manufacturing Process pane or Geometric Cost Drivers pane, right-click the GCD to which you want to assign the operation, and select Edit Operation. Also note that the Weld GCD's Production Mechanism field must be set to Robotic for either Laser Welding or Electron Beam operations to cost successfully.

You must manually assign Weld Prep and/or Weld Cleanup operations to each weld that requires them. Weld Prep supports the following operations:

- Bevel Cutting
- Grinding
- Wire Brushing

Weld Clean Up supports the Grinding operation.

Welding Operation Feasibility

The welding operations have feasibility requirements that are based on the Weld Type and Production Mechanism which were specified in the Welding dialog when the weld was created, or were determined by extraction from the CAD model. Following are the requirements:

- Manual MIG Welding: both the following must hold:
 - Weld type is not Spot.
 - Production Mechanism is not Robotic.
 - Travel speed data is available (see [MIG Welding Operation Weld Time](#))
- Manual TIG Welding: both the following must hold:
 - Weld type is not Spot.
 - Production Mechanism is not Robotic.
- Manual Spot Welding: both the following must hold:
 - Weld type is Spot.
 - Production Mechanism is not Robotic.
- Robotic MIG Welding: both the following must hold:
 - Weld type is not Spot.
 - Production Mechanism is Robotic.
 - Travel speed data is available (see [MIG Welding Operation Weld Time](#))
- Robotic TIG Welding: both the following must hold:
 - Weld type is not Spot.
 - Production Mechanism is not Robotic.
- Robotic Spot Welding: both the following must hold:
 - Weld type is Spot.

- Production Mechanism is Robotic.
- Electron Beam Welding: all the following must hold:
 - Weld type is not Spot.
 - Production Mechanism is Robotic.
 - Weld depth does not exceed the value of the cost model variable **EBWMaximumWeldDepth** (100mm in starting point VPEs).
- Laser Welding: all the following must hold:
 - Weld type is not Spot.
 - Production Mechanism is Robotic.
 - Weld depth does not exceed the value of the cost model variable **LWMaximumWeldDepth** (100mm in starting point VPEs).

Weld Prep Operation Feasibility

The Weld Prep operation Bevel Cutting is feasible for a given weld only if the Weld Type is *not* any of the following:

- Spot
- Fillet
- Square Groove
- Plug
- Slot
- Tack
- Wrap Tie

Material Selection

The processes in this group do not use any material; material cost is always 0 for all processes. Welding wire is considered to be expendable tooling—see [MIG Welding Expendable Tooling Calculation](#) and [Spot Welding Expendable Tooling Calculation](#).

Machine Selection

For most processes in this process group, machine selection works as follows (exceptions include Electron Beam Welding and Laser Welding—see below):

- By default in starting point VPEs, the lowest-overhead virtual machine is selected.
- If the cost model variable **preferVirtualMachines** is **false** (it is **true** in starting point VPEs), the lowest-overhead default machine is selected, if there is one.
- Otherwise, the lowest-overhead machine is selected (regardless of whether it is a virtual machine). You can manually select a non-default machine.

Overhead, here, is given by the sum of the machine properties **Direct Overhead Rate** and **Indirect Overhead Rate**.

For Electron Beam and Laser Welding, aPriori selects the feasible machine with the lowest per-part overhead rate.

Overhead rate is given by the sum of the machine properties **Direct Overhead Rate** and **Indirect Overhead Rate**. Per-part overhead rate is calculated by amortizing this value over the maximum number of parts that can fit in the machine (considering both lengthwise and widthwise orientations, with space between parts specified by the cost model variable **EBWMinPartSpacing** or **LWMinPartSpacing**--50mm in starting point VPEs) or over the number of parts specified by the user with the setup option **Number of Parts in the Machine per Cycle**.

An Electron Beam Welding machine is feasible if both the following hold:

- Machine can accommodate the weight and dimensions of the part (based on the machine properties **Max Weight**, **Working Height**, **Working Width**, and **Working Length**).
- Value of the machine property **Is Load Lock Machine** matches the value of the setup option **Is the EB Welding Machine a Load Lock Machine** (**false**, by default).

A Laser Welding machine is feasible if the machine can accommodate the weight and dimensions of the part (based on the machine properties **Max Weight**, **Working Height**, **Working Width**, and **Working Length**).

For Electron Beam and Laser Welding, aPriori selects only from virtual machines, if there is a feasible preferred machine and the cost model variable **preferVirtualMachines** is set to **true** (the default in starting point VPEs). If there is no feasible virtual machine, or if the cost model variable **preferVirtualMachines** is set to **false**, aPriori selects the default machine, if it is feasible. Otherwise, aPriori selects from all machines. A machine is virtual if the machine property **isVirtualMachine** (typically displayed as **Is Virtual Machine**) is **true**.

Cost Algorithms and Calculations

This section details how costs are calculated by aPriori. This section covers formulas in the following areas:

- Yields
- Adhesive Bonding Formulas
- Lock Bolt Formulas
- Threaded Insert Formulas
- Cap Sealing Formulas
- Fay Sealing Formulas
-
- Fillet Sealing Formulas
- Rivet Process Formulas
- Manual MIG Welding and Robotic MIG Welding
- Manual TIG Welding and Robotic TIG Welding
- Manual Spot Welding and Robotic Spot Welding
- Pick and Place Formulas

- Weld Prep Calculations
- Weld Clean Up Calculations
- Mechanical Assembly Calculations

Yields

These formulas are used by all the processes in this process group.

Final Yield = Final Output Volume / Input Volume

Final yield affects material, labor, and overhead costs per part. It is the fraction of parts created by this process in the current production scenario that will survive as good parts once any secondary processes are completed. That is, final yield is the fraction of parts created by this process that are *not* discarded as scrap parts, either by this process or by a downstream process. Final yield depends on the following:

- Final Output Volume (product of the annual volume and number of production years, specified in the Production Scenario screen of the Cost Guide)
- Input volume (see the formula below). This is the total number of parts produced by this process, including all parts discarded as scrap from this process or downstream processes.

Input Volume = Local Output Volume + Number of Scrap Parts for This Process

Input volume is the total number of parts produced by this process in the current scenario, including all parts discarded as scrap from this process or downstream processes. It is the sum of the following:

- Local output volume (see the formula below). This is the number of parts produced by this process, excluding parts discarded as scrap by this process, but including parts that are discarded as scrap by downstream processes.
- Number of scrap parts for this process (see the formula below)

Local Output Volume = Final Output Volume + Number of Scrap Parts Downstream

Local output volume is the number of parts produced by this process in the current scenario, excluding parts discarded as scrap by this process, but including parts that are discarded as scrap by downstream processes. It is the sum of the following:

- Final output volume (product of volume and number of production years, specified in the Production Scenario screen of the Cost Guide)
- Number of Scrap Parts Downstream. This is the number of parts discarded as scrap by downstream processes.

Number of Scrap Parts for This Process = (Local Output Volume / Good Part Yield) – Local Output Volume

Number of scrap parts for this process is the number of parts produced by this process in the current scenario that are discarded as scrap by this process, before any downstream process is performed on them. It is a function of the following:

- Local output volume (see the formula above)

- Good part yield (specified by the machine property **Good Part Yield**). This is the fraction of parts produced by this process that are not discarded as scrap by this process but may be discarded as scrap by downstream processes.

Adhesive Bonding Formulas

Adhesive bonding formulas are covered in the following sections:

- [Cycle Time Formulas for Adhesive Bonding](#)
- [Expendable Tooling for Adhesive Bonding](#)

Cycle Time Formulas for Adhesive Bonding

Cycle Time = Process Time * Cycle Time Adjustment Factor

Cycle time is the product of the following:

- Process time (see formula)
- Cycle time adjustment factor: specified by the cost model variable **cycleTimeAdjustmentFactor** (1 in starting point VPEs). Administrators can customize this value in order to globally adjust cycle times.

Process Time = Bond Time + Degrease Time

Process time is the sum of the following:

- Bond time (see formula)
- Degrease time (see formula)

Bond Time = Surface Area Bonded / Application Area Rate

This is the time to apply adhesive to the relevant surfaces of the assembly components. It depends on the following:

- Surface Area Bonded: the surface area to which adhesive is applied, expressed in square meters--see formula.
- Application Area Rate: the rate at which adhesive is applied. This is specified in m²/minute by the machine property **Application Rate**, and is converted to m²/sec for use in this formula.

Surface Area Bonded = Assembly Surface Area * Bonded Area

The surface area to which adhesive is applied is the product of the following:

- Assembly surface area: this is the sum of the surface areas of all the assembly's component parts (as determined by geometry extraction).
- Bonded area: this is the fraction of the total assembly surface area to which adhesive is applied. By default in starting point VPEs, this is 0.1. Administrators can customize the default, and specify the default *percentage* of total surface area by using the cost model variable **defaultPercentBonded** (10 in starting point VPEs). Users can override the default on a per-part basis, and specify a percentage of surface area with the setup option [Bonded Area](#).

This value is converted to square meters for use in the formulas Bond Time and Degrease Time, as well as in the calculation for [Expendable Tooling for Adhesive Bonding](#).

Degrease Time = Surface Area Bonded / Degrease Application Rate

This is the time to prepare the surface for the application of adhesive. It depends on the following:

- Surface area bonded: this is the surface area to be degreased, which is the surface area to which adhesive is subsequently to be applied--see formula, above.
- Degrease Application Rate: the rate at which degreasing solution is applied. This is specified in m²/minute by the cost model variable **degreaseApplicationRate**, (0.03 m²/minute in starting point VPEs), and is converted to m²/sec for use in this formula.

Expendable Tooling for Adhesive Bonding

$$\text{Expendable Tooling Cost Per Part} = \text{Surface Area Bonded} * \text{Resin Density} * \text{Applied Resin Thickness} * \text{Resin Material Factor} * \text{Resin Material Price}$$

This is the cost per part for adhesive resin. It is the product of the following:

- Surface Area Bonded: the surface area to which adhesive is applied, expressed in square meters--see the formula for Surface Area Bonded in [Cycle Time Formulas for Adhesive Bonding](#).
- Resin density: density of the adhesive, specified in kg/m³ by the cost model variable **resinDensity** (1100kg/m³ in starting point VPEs).
- Applied resin thickness: this is the thickness of the coat of adhesive applied to the surfaces. It is specified in meters by the cost model variable **defaultResinThickness** (0.002m in starting point VPEs).
- Resin material factor: this factor adjusts the cost upward in order to account for adhesive that is lost during application. The factor is 1.1 in starting point VPEs, indicating that the volume of material lost is equal to 1/10th of the volume of material that is successfully applied to assembly surfaces. Administrators can customize the factor with the cost model variable **resinMaterialFactor**.
- Resin material price: this is the price per unit mass for adhesive, expressed in USD per Kg. It is looked up by adhesive type (Acrylic, Epoxy, or Urethane, in starting point VPEs) in the lookup table **adhesiveResins**. The adhesive type is Acrylic by default in starting point VPEs. Administrators can customize the default with the cost model variable **defaultAdhesiveResin**. Users can override the default on a per-part basis with the setup option [Adhesive Resin Type](#).

adhesiveResins	
Adhesive Type	Cost Per Kg (USD / kg)
Acrylic	105.28
Epoxy	461.00
Urethane	444.40

Lock Bolt Formulas

Cycle Time =

Final Bolt Placement Time + Final Collar Placement Time + Final Lock Time

The Lock Bolt Install operation models three tasks:

- Bolt placement: placing the bolt before placement of the collar.
- Collar placement: placing the collar on the bolt prior to tightening.
- Collar Tightening: tightening the collar with a hand tool.

Consequently, cycle time is the sum of the following:

- Final bolt placement time: this is the time to place the bolt, including any extra time required due to vision difficulties or obstructions. See formula.
- Final collar placement time: this is the time to place the collar, including any extra time required due to vision difficulties or obstructions. See formula.
- Final Lock Time: this is the time to tighten the collar, including any extra time required due to vision difficulties or obstructions. See formula.

Final Bolt Placement Time = Bolt Placement Time + Bolt Extra Time

Final bolt placement time is the sum of the following:

- Bolt placement time: this is the time to place the bolt, in the absence of obstructions or vision difficulties. It is looked up by process name ('**Lock Bolt**') and task name ('**Bolt Placement**') in the lookup table **tblMechanicalOperationTimes** (3 seconds in starting point VPEs).
- Bolt extra time: this accounts for any extra time required to place the bolt due to an obstruction or vision problem. The extra time is looked up in the lookup table **tblMechanicalOperationTimes** by the following:
 - Process name ('**Lock Bolt**')
 - Task name ('**Bolt Placement**')
 - Setting of the PSO **Lock Bolt Obstructed Or Vision**.

The extra time is 0 if the PSO setting is **No obstructed access or vision problem** (the default in starting point VPEs).

Process	Operation	Operation Time (s)	Blind Or Obstructed Time (s)	Blind And Obstructed Time (s)
Lock Bolt	Bolt Placement	3.00	2.50	4.00
Lock Bolt	Collar Placement	2.00	2.50	4.00
Mechanical Assembly	Nut Insert	1.50	2.50	4.00
Mechanical Assembly	Press Fit	7.50	2.50	4.00
Mechanical Assembly	Rivet	8.00	2.50	4.00
Mechanical Assembly	Screw Tighten - Manual	12.00	5.00	8.00
Mechanical Assembly	Screw Tighten - Power	6.00	2.50	4.00
Mechanical Assembly	Snap Fit	3.00	2.50	4.00
Mechanical Assembly	Tab Bend	3.50	2.50	4.00
Threaded Insert	Tang Break	1.00	2.50	4.00
Threaded Insert	Threaded Insert Op	1.00	2.50	4.00

Final Collar Placement Time = Collar Placement Time + Collar Extra Time

Final collar placement time is the sum of the following:

- Collar placement time: this is the time to place the collar, in the absence of obstructions or vision difficulties. It is looked up by process name ('Lock Bolt') and task name ('Collar Placement') in the lookup table **tblMechanicalOperationTimes** (2 seconds in starting point VPEs).
- Collar extra time: this accounts for any extra time required to place the collar due to an obstruction or vision problem. The extra time is looked up in the lookup table **tblMechanicalOperationTimes** by the following:
 - Process name ('Lock Bolt')
 - Task name ('Collar Placement')
 - Setting of the PSO **Lock Bolt Collar and Hand Tool Obstructed or Blind**.

The extra time is 0 if the PSO setting is **No obstructed access or vision problem** (the default in starting point VPEs).

Final Lock Time = Lock Time + Collar Extra Time

Final lock time is the sum of the following:

- Lock time: this is the time to tighten the collar, in the absence of obstructions or vision difficulties. It is specified by the machine property **Lock Speed** (1 second for the machines in starting point VPEs).
- Collar extra time: this accounts for any extra time required to tighten the collar due to an obstruction or vision problem. It is assumed to be the same as any extra time required to *place* the collar, since placing it and tightening it require access to bolt from the same direction. The extra time is looked up in the lookup table **tblMechanicalOperationTimes** by the following:
 - Process name ('Lock Bolt')
 - Task name ('Collar Placement')
 - Setting of the PSO **Lock Bolt Collar and Hand Tool Obstructed or Blind**.

The extra time is 0 if the PSO setting is **No obstructed access or vision problem** (the default in starting point VPEs).

Threaded Insert Formulas

Cycle Time = Final Threaded Insert Insert Time + Final Tang Break Time

The Threaded Insert operation models three tasks:

- Threaded Insert placement: insertion of the threaded insert before the tang is broken.
- Tang breaking: the tang blocks the hole during insertion; it must be removed subsequent to insertion.

Consequently, cycle time is the sum of the following:

- Final threaded insert insert time: this is the time to insert the threaded insert, *including* any extra time required due to vision difficulties or obstructions. See formula.
- Final tang break time: this is the time to break the tang, including any extra time required due to vision difficulties or obstructions. See formula.

Final Threaded Insert Insert Time = Threaded Insert Insert Time + Threaded Insert Insert Extra Time

The final time to insert the threaded insert is the sum of the following:

- Threaded insert insert time: time to insert the threaded insert, *not* including any extra time required due to vision difficulties or obstructions. This is specified by the machine property **Insert Time** (4 seconds for the default machine in starting point VPEs).
- Threaded insert insert extra time: this accounts for any extra time required, due to an obstruction or vision problem, to insert the threaded insert. The extra time is looked up in the lookup table **tbiMechanicalOperationTimes** by the following:
 - Process name ('Threaded Insert')
 - Task name ('Threaded Insert Op')
 - Setting of the PSO **Threaded Insert Obstructed Or Vision**.

The extra time is 0 if the PSO setting is **No obstructed access or vision problem** (the default in starting point VPEs).

Process	Operation	Operation Time (s)	Blind Or Obstructed Time (s)	Blind And Obstructed Time (s)
Lock Bolt	Bolt Placement	3.00	2.50	4.00
Lock Bolt	Collar Placement	2.00	2.50	4.00
Mechanical Assembly	Nut Insert	1.50	2.50	4.00
Mechanical Assembly	Press Fit	7.50	2.50	4.00
Mechanical Assembly	Rivet	8.00	2.50	4.00
Mechanical Assembly	Screw Tighten - Manual	12.00	5.00	8.00
Mechanical Assembly	Screw Tighten - Power	6.00	2.50	4.00
Mechanical Assembly	Snap Fit	3.00	2.50	4.00
Mechanical Assembly	Tab Bend	3.50	2.50	4.00
Threaded Insert	Tang Break	1.00	2.50	4.00
Threaded Insert	Threaded Insert Op	1.00	2.50	4.00

Final Tang Break Time = Tang Break Time + Tang Break Extra Time

Final tang break time is the sum of the following:

- Tang break time: this is the time to break the tang, in the absence of obstructions or vision difficulties. It is looked up by process name ('Threaded Insert') and task name ('Tang Break') in the lookup table **tblMechanicalOperationTimes** (1 second in starting point VPEs).
- Tang break extra time: this accounts for any extra time required to break the tang due to an obstruction or vision problem. The extra time is looked up in the lookup table **tblMechanicalOperationTimes** by the following:
 - Process name ('Threaded Insert')
 - Task name ('Tang Break')
 - Setting of the PSO **Tang Break Obstructed Or Vision**.

The extra time is 0 if the PSO setting is **No obstructed access or vision problem** (the default in starting point VPEs).

Cap Sealing Formulas

Cycle Time =

(Process Time / Number of Operators) * Cycle Time Adjustment Factor

Cycle time depends on the following:

- Process time (see formula)
- Number of operators (specified by the machine property **Number of Operators**).
- Cycle time adjustment factor: specified by the cost model variable **cycleTimeAdjustmentFactor**; 1 in aPriori starting point VPEs. If you want to model an unbalanced, push assembly line, set **cycleTimeAdjustmentFactor** to a value greater than 1 in order to account for the cost of extra buffer capacity.

Process Time = Total Cap Sealed Holes * Seal Time

Process time is the product of the following:

- Total cap sealed holes: this is the number of holes to be sealed. By default, it is the number of the assembly's holes that are within a certain size range (see **Number of Holes Cap Sealed**); users can override the default with the setup option **Number of Holes Cap Sealed**.
- Seal time: this is the time to seal one hole. By default, it is specified by the cost model variable **defaultSealTime** (5 seconds, in starting point VPEs). Users can override the default with the setup option **Time to Cap Seal One Hole**.

Additional Direct Costs =

Sealant Material Price * (Cap Sealant Holes * (Seal Time * Nozzle Flow Rate))

Additional direct costs account for the cost of sealant material, which depends on the following:

- Sealant material price: by default this is looked up by **Sealant Type** in the lookup table **sealant**. Users can override the default with the setup option **Sealant Price**.

- Cap sealant holes: this is the number of holes to be sealed. By default, it is the number of the assembly's holes that are within a certain size range (see [Number of Holes Cap Sealed](#)); users can override the default with the setup option [Number of Holes Cap Sealed](#).
- Seal time: this is the time to seal one hole. By default, it is specified by the cost model variable **defaultSealTime** (5 seconds, in starting point VPEs). Users can override the default with the setup option [Time to Cap Seal One Hole](#).
- Nozzle flow rate: specified by the cost model variable **nozzleFlowRate** (0.01 kg/s in starting point VPEs).

Fay Sealing Formulas

Cycle Time =

(Process Time / Number of Operators) * Cycle Time Adjustment Factor

Cycle time depends on the following:

- Process time (see formula)
- Number of operators (specified by the machine property **Number of Operators**).
- Cycle time adjustment factor: specified by the cost model variable **cycleTimeAdjustmentFactor**; 1 in aPriori starting point VPEs. If you want to model an unbalanced, push assembly line, set **cycleTimeAdjustmentFactor** to a value greater than 1 in order to account for the cost of extra buffer capacity.

Process Time = Bond Time + Degrease Time

Process time is the sum of the following:

- Bond time (see formula)
- Degrease time (see formula)

Bond Time = Surface Area Bonded / Application Area Rate

This is the time to apply adhesive to the relevant surfaces of the assembly components. It depends on the following:

- Surface Area Bonded: the surface area to which sealant is applied, expressed in square meters--see formula.
- Application Area Rate: the rate at which sealant is applied. This is specified in m²/minute by the machine property **Application Rate**, and is converted to m²/sec for use in this formula.

Surface Area Bonded = Assembly Surface Area * Bonded Area

Surface area bonded is the product of the following:

- Assembly surface area: this is the sum of the surface areas of all the assembly's component parts (as determined by geometry extraction).
- Bonded area: this is the fraction of the total assembly surface area to be bonded. By default, this is specified by the cost model variable **defaultPercentBonded** (10%

in starting point VPEs). Users can override the default with the setup option [Bonded Area](#).

Note that this value is converted to square meters for use in the cycle time and expendable tooling formulas.

Degrease Time = Surface Area Bonded / Degrease Application Rate

This is the time to prepare the surface for the application of sealant. It depends on the following:

- Surface area bonded: this is the surface area to be degreased, which is the surface area to which sealant is subsequently to be applied--see formula, above.
- Degrease Application Rate: the rate at which degreasing solution is applied. This is specified in m²/minute by the cost model variable **degreaseApplicationRate**, (0.03 m²/minute in starting point VPEs), and is converted to m²/sec for use in this formula.

Expendable Tooling Cost = Surface Area Bonded * Sealant Density * Applied Resin Thickness * Resin Material Factor * Sealant Material Price

Expendable tooling cost is the product of the following:

- Surface area bonded: See formula. Note that this value is converted to square meters for use in this formula.
- Sealant density: specified by the cost model variable **sealantDensity** (1570 kg/m³ in starting point VPEs).
- Applied resin thickness: specified by the cost model variable **defaultResinThickness** (0.002 meters, in starting point VPEs).
- Resin material factor: accounts for the loss of material during application. This is specified by the cost model variable **resinMaterialFactor** (1.1 in starting point VPEs).
- Sealant material price: by default this is looked up by [Sealant Type](#) in the lookup table **sealant**. Users can override the default with the setup option [Sealant Price](#).

Fillet Sealing Formulas

Cycle Time = (Process Time / Number of Operators) * Cycle Time Adjustment Factor

Cycle time depends on the following:

- Process time (see formula)
- Number of operators (specified by the machine property **Number of Operators**).
- Cycle time adjustment factor: specified by the cost model variable **cycleTimeAdjustmentFactor**; 1 in aPriori starting point VPEs. If you want to model an unbalanced, push assembly line, set **cycleTimeAdjustmentFactor** to a value greater than 1 in order to account for the cost of extra buffer capacity.

Process Time = Seal Time * Applied Sealant

Process time is the product of the following:

- Seal time: this is the time per unit length required to apply the sealant (in seconds per millimeter). By default, it is specified by the machine property **Application Rate**. Users can override the default with the setup option [Time to Seal per Length](#).
- Applied sealant: this is the total length of sealant to be applied. By default, this is assumed to be a certain fraction of the sum of the subcomponent perimeters (where each subcomponent's perimeter is twice the sum of its length and width). The fraction is specified by the cost model variable **sealantFactor** (0.1 in starting point VPEs). Users can override the default with the setup option [Length of Sealant Required](#).

Additional Direct Costs = Sealant Material Price * Bond Time * Nozzle Flow Rate

Expendable tooling cost is the product of the following:

- Sealant material price: Sealant material price: by default this is looked up by [Sealant Type](#) in the lookup table **sealant**. Users can override the default with the setup option [Sealant Price](#).
- Bond time: see the formula for Process Time.
- Nozzle flow rate: specified by the cost model variable **nozzleFlowRate** (0.01 kg/s in starting point VPEs).

Rivet Process Formulas

Rivet Time = (Labor Time / Number of Operators) * Cycle Time Adjustment Factor

Cycle time depends on the following:

- Labor time (see formula)
- Number of operators (specified by the machine property **Number of Operators**).
- Cycle time adjustment factor: specified by the cost model variable **cycleTimeAdjustmentFactor**; 1 in aPiori starting point VPEs. If you want to model an unbalanced, push assembly line, set **cycleTimeAdjustmentFactor** to a value greater than 1 in order to account for the cost of extra buffer capacity.

Labor Time = Rivet Time + Rivet Extra Time

Labor time is the sum of the following:

- Rivet time (see formula)
- Rivet extra time (see formula)

Rivet Time = Rivet Time per Hole * Number of Riveted Holes

Rivet time is the sum of the following:

- Rivet time per hole: this is the time to rivet one hole, in the absence of obstructions or vision difficulties. It is looked up by process group ('**Assembly**') and

process name ('Rivet') in the lookup table **tblMechanicalOperationTimes** (3 seconds in starting point VPEs).

- Number of riveted holes (see formula)

Rivet Extra Time = Rivet Extra Time per Hole * Number of Riveted Holes

- Rivet extra time per hole: this accounts for any extra time required to rivet the hole due to an obstruction or vision problem. The extra time is looked up in the lookup table **tblMechanicalOperationTimes** by the following:
 - Process group name ('Assembly')
 - Process name ('Rivet')
 - Setting of the PSO **Rivet Obstructed Or Vision**.

The extra time is 0 if the PSO setting is **No obstructed access or vision problem** (the default in starting point VPEs).

- Number of riveted holes (see formula)

Process	Operation	Operation Time (s)	Blind Or Obstructed Time (s)	Blind And Obstructed Time (s)
Assembly	Rivet	8.00	2.50	4.00
Assembly	Riveting	8.00	2.50	4.00
Lock Bolt	Bolt Placement	3.00	2.50	4.00
Lock Bolt	Collar Placement	2.00	2.50	4.00
Mechanical Assembly	Nut Insert	1.50	2.50	4.00
Mechanical Assembly	Press Fit	7.50	2.50	4.00
Mechanical Assembly	Rivet	8.00	2.50	4.00
Mechanical Assembly	Screw Tighten - Manual	12.00	5.00	8.00
Mechanical Assembly	Screw Tighten - Power	6.00	2.50	4.00
Mechanical Assembly	Snap Fit	3.00	2.50	4.00
Mechanical Assembly	Tab Bend	3.50	2.50	4.00
Threaded Insert	Tang Break	1.00	2.50	4.00
Threaded Insert	Threaded Insert Op	1.00	2.50	4.00

**Number of Riveted Holes =
Number of Riveted Simple Holes + Number of Riveted Complex Holes**

By default, the number of riveted holes is the sum of the following:

- Number of riveted simple holes: this is the number of SimpleHole GCDs whose diameter is within range (see below).
- Number of riveted complex holes: this is the number of ComplexHole GCDs whose MEC diameter (diameter of the largest circle that fits inside the hole) is in range.

A diameter or MEC diameter is in range if it is between the values of the following cost model variables:

- **minRivetDiameter** (2mm in starting point VPEs)
- **maxRivetDiameter** (8mm in starting point VPEs)

Users can override the default number of holes with the setup option **Riveted Hole Count**.

Manual MIG Welding and Robotic MIG Welding

This section has the following subsections:

- MIG Welding Operation Weld Time
- MIG Welding Weld Weight
- Manual MIG Welding Accounting Calculations
- Manual MIG Welding Process Cycle Time
- Robotic MIG Welding Labor Time
- Robotic MIG Welding Accounting Calculations
- MIG Welding Expendable Tooling Calculation
- Additional Direct Costs for MIG Welding

MIG Welding Operation Weld Time

The formulas in this section are used by the Welding operation for both Manual MIG Welding and Robotic MIG Welding.

Weld Time = Arc Time + Tack Time + Gun Manipulation Time + Gun Clean Time

For each Weld GCD, weld time is the sum of the following:

- Arc time (see formula)
- Tack time (see formula)
- Gun manipulation time (see formula)
- Gun clean time (see formula)

Arc Time

Arc time is the time for the arcing phase of welding—it excludes arc time for tack welding. Arc time is determined in one of two ways:

- Volumetric Rate Method: based on the following:
 - Weld volume
 - Deposition rate (derived from the machine properties **Wire Feed Rate** and **Wire Diameter**)
- Linear Rate Method: based on the following:
 - Weld length
 - Travel rate (derived from **Weld Throat** and **Filler Material Type**, or specified by the user)
 - Number of passes (derived from **Weld Throat**, or specified by the user)

The Linear Rate Method is used by default in starting point VPEs. Administrators can customize the default (for both MIG and TIG welding) by setting the cost model variable **weldLinearFeedRate** to **false**. Users can override the default on a per-weld basis with the setup option **Weld Cycle Time Method**.

See the formulas for **Volume Method Arc Time** and **Length Method Arc Time**, below.

Machine Variables			Weld Variables			Material Variables
Machine Current	Machine Voltage	Travel Speed (mm / s)	Throat Thickness (mm)	Wire Diameter (mm)	Material Type	
34.00	16.00	4.17	0.05	0.60	Steel	
36.00	16.00	4.17	0.11	0.60	Steel	
39.00	16.00	4.17	0.16	0.60	Steel	
42.00	16.00	4.17	0.21	0.60	Steel	
45.00	16.00	4.17	0.27	0.60	Steel	
47.00	17.00	4.17	0.32	0.60	Steel	
50.00	17.00	5.83	0.37	0.60	Steel	
53.00	17.00	5.83	0.42	0.60	Steel	
56.00	18.00	5.83	0.48	0.60	Steel	

- Arc time factor: this adjusts arc time according to weld type. It is looked up by weld type in the lookup table **tblWeldArcTimeFactor**.

Weld Type	Arc Time Factor
Bevel Groove	1.00
Fillet	1.00
Flared Bevel Groove	0.40
Flared V-Groove	0.60
J-Groove	1.50
Plug	1.00
Slot	1.00
Spot	1.00
Square Groove	2.00
Tack	1.00
U-Groove	1.70
V-Groove	1.00
Wrap Tie	1.00

Theoretical Arc time = GCD Volume / (Arc Efficiency * Deposition Rate)

Theoretical arc time depends on the following:

- GCD volume (based on geometry extraction or user-specified weld dimensions and weld type)
- Arc efficiency: fraction of welding wire that ends up in the weld and is not lost to spatter and evaporation. This value is specified by the cost model variable **arcEfficiency** (0.5 in starting point VPEs).
- Deposition rate (see formula)

Deposition rate = Pi * (Wire Diameter/2)² * Wire Feed Rate

Deposition rate is the weld volume per unit time that is deposited during the arcing phase. It depends on the following:

- Wire diameter (specified by the machine property **Wire Diameter**)
- Wire feed rate is the wire length per unit time that is deposited during the arcing phase (specified by the machine property **Wire Feed Rate**)

**Gun Manipulation Time =
Number of Weld Segments * Gun Placement Time per Segment**

Gun manipulation time includes all tasks between welds such as lifting the hood or visor, moving to the next location, repositioning the torch, readying to strike, and so forth. It is the product of the following:

- Number of weld segments (specified by the user or geometry extraction)
- Gun placement time per segment (specified by the machine property **Gun Placement Time**)

Gun Clean Time = Arc Time * Gun Clean Time per Unit Arc Time

Gun clean time is the time for robotic cleaning of weld spatter from around the contact tip and nozzle. It is the product of the following:

- Arc time (see formula)
- Gun clean time per unit arc time (specified by the machine property **Gun Clean Time per Arc**)

Operation Tack Time Calculations

Tack Time = Tack Arc Time + Tack Gun Manipulation Time + Tack Gun Clean Time

If tacking is enabled (see below) tack time is the sum of the following:

- Tack arc time (see formula)
- Tack gun manipulation time (see formula)
- Tack gun clean time (see formula)

If tacking is not enabled tack time is 0.

For robotic welding, by default in starting point VPEs, operators are assumed to perform tack welding in order to prepare the workpieces. VPE administrators can customize the default with the cost model variable **enableTackingWithRoboticWelding**. Users can override the default with the setup option [Enable Tacking](#).

For manual welding, the cost model always assumes that tacking is performed.

Tack Arc Time = Theoretical Tack Arc Time * Arc Time Standard

Tack arc time is the product of the following:

- Theoretical tack arc time (see formula)
- Arc time standard: multiplier to account for any operator pauses or breaks between cycles. Specified by the machine property **Arc Time Std**.

Theoretical Tack Arc Time = Tack Volume / Arc Efficiency * Deposition Rate

Theoretical tack arc time depends on the following:

- Tack volume (see formula for appropriate weld type)
- Arc efficiency: fraction of welding wire that ends up in the weld and is not lost to spatter and evaporation. This value is specified by the cost model variable **arcEfficiency** (0.5 in starting point VPEs).
- Deposition rate (see formula)

Tack Volume for Slot and Plug Welds = gcd.volume * tackLength / tackPitch

The cost model assumes that the cross-section area of a tack weld is the same as the cross-section area of the robot-created weld—they differ only in length. For slot and plug welds, it assumes that the ratio of tack volume to the volume of the robot-created weld is the same as the ratio of tack length to tack pitch. (Tack pitch is the distance from the start of one tack weld to the start of the next tack weld.)

Tack volume for slot and plug welds depends on the following:

- GCD volume (based on geometry extraction or user-specified weld dimensions and weld type)
- Tack length (specified by the machine property **Tack Length**)
- Tack pitch (specified by the machine property **Tack Pitch**)

Tack Volume for Non-slot, Non-plug Welds = Tack Cross-section Area * tackLength * numTacks

Tack volume for welds other than slot and plug welds is the product of the following:

- Tack cross-section area (see formula)
- Tack length. This is the length of a single tack weld, specified by the machine property **Tack Length**.
- Number of tacks (see formula)

Tack Cross-section Area = Weld Volume / Weld Length * Number of Weld Segments

Tack cross-section area is the area of a tack weld cross-section normal to the weld's length direction (the direction of motion of the gun during arcing). It depends on the following:

- Weld volume
- Weld length
- Number of weld segments

Number of Tacks for Slot and Plug Welds= Number of Weld Segments

For slot and plug welds, the number of tacks is the same as the number of weld segments specified by the user or determined by geometry extraction.

Number of Tacks for Non-slot, Non-plug Welds= Roundup(Arcing Length / Tack Pitch)

For non-slot, non-plug welds, the number of tacks is the minimum number of tack welds required to have a tack weld at the beginning and end of the weld GCD, with tack welds in between spaced by no more than tack pitch. Number of tacks is the quotient of the following, rounded *up* the nearest whole number:

- Arcing length (see formula)
- Tack pitch (specified by the machine property **Tack Pitch**)

Arcing Length = Segment Length * Number of Segments

Arcing length is the total distance the point of deposition travels during arcing phase for all weld segments. It is the product of the following:

- Segment length (specified by the user or determined by geometry extraction)
- Number of segments (specified by the user or determined by geometry extraction)

Tack Gun Manipulation Time = Number of Tacks * Gun Placement Time per Segment

For tacking, gun manipulation time is the product of the following:

- Number of tacks (see formula)
- Gun placement time per segment (specified by the machine property **Gun Placement Time**)

Tack Gun Clean Time = Tack Arc Time * Gun Clean Time per Unit Arc Time

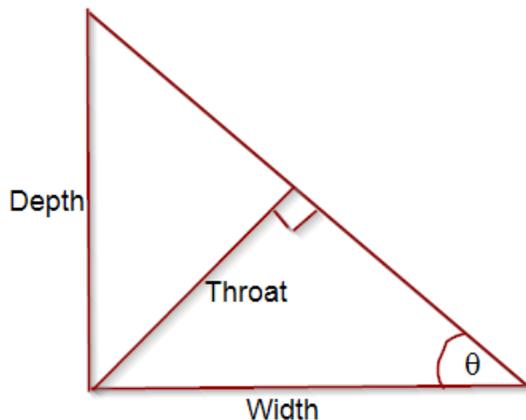
Gun clean time is the time for robotic cleaning of weld spatter from around the contact tip and nozzle. The gun cleaning time associated with tacking is the product of the following:

- Tack arc time (see formula)
- Gun clean time per unit arc time (specified by the machine property **Gun Clean Time per Arc**)

Weld Throat

Weld throat is the shortest distance from weld root to weld face, that is, the distance from root to face along the direction perpendicular to the face.

For the purpose of determining the number of welding passes required for a given weld, the weld throat calculation assumes a fillet weld:



Here, θ is $\text{atan}(\text{Depth}/\text{Width})$, so weld throat is given by this formula:

$$\text{Weld Throat} = \text{Weld Width} * \sin(\arctan(\text{Weld Depth} / \text{Weld Width}))$$

For the purpose of determining travel speed, throat for an individual welding pass is determined in one of two ways:

- If the weld type is **Plug** or **Slot**, the throat is estimated as follows:

$\sqrt{\text{Weld Width} * \text{Weld Depth} / \text{Number of Weld Passes}}$

- If weld type is *not* **Plug** or **Slot**, the throat is estimated as follows:

$\sqrt{(\text{Weld Cross-sectional Area} / \text{Number of Weld Passes}) * 2}$

Note that the formula for Arc Time includes an adjustment, Arc Time Factor, that reflects the weld type, which is specified by the lookup table **tblWeldArcTimeFactor**.

Weld Type	Arc Time Factor
Bevel Groove	1.00
Fillet	1.00
Flared Bevel Groove	0.40
Flared V-Groove	0.60
J-Groove	1.50
Plug	1.00
Slot	1.00
Spot	1.00
Square Groove	2.00
Tack	1.00
U-Groove	1.70
V-Groove	1.00
Wrap Tie	1.00

See also the formula for **Length Method Arc Time** in MIG Welding Operation Weld Time and TIG Welding Operation Weld Time.

MIG Welding Weld Weight

The formula in this section is used by both Manual and Robotic MIG Welding.

Weld Weight = GCD Volume * Weld Density

The weight of each weld GCD is used to calculate the total weld weight, which affects expendable tooling costs, as well as total assembly weight, which affects Pick and Place costs. The weight in kilograms of each weld GCD is the product of the following:

- GCD Volume (based on geometry extraction or user-specified weld dimensions and weld type)
- Weld density: specified in kg/m³ by the machine property **Weld Density**. aPriori converts this value to kg/mm³.

Manual MIG Welding Accounting Calculations

Amortized Batch Setup =

$(\text{Setup Time} * (\text{Labor Rate} + \text{Direct Overhead Rate})) / \text{Batch Size}$

Amortized batch setup depends on the following:

- Setup time (specified as the machine property **Setup Time**)
- Labor rate (specified by the machine property **Labor Rate**)
- Direct overhead rate (see [Direct and Indirect Overhead](#))

- Batch size (specified in the **Production Scenario** screen of the Cost Guide)

$$\text{Labor Cost} = \text{Labor Time} * \text{Labor Rate} / \text{Final Yield}$$

Labor cost depends on the following:

- Labor time (see formula)
- Labor rate (specified by the machine property **Labor Rate**)
- Final yield (see [Yields](#))

$$\text{Labor Time} = \text{Operation Weld Times} * \text{Labor Time Standard}$$

Labor time is the product of the following:

- Operation weld times: sum of the weld times and tack times of all child operations—see [MIG Welding Operation Weld Time](#).
- Labor time standard: specified as the machine property **Labor Time Standard**. This multiplier is used to account for otherwise unaccounted for factors that affect labor time, such as operator fatigue or time spent by the operator for cleaning or maintenance.

Note that labor time is independent of the number of operators, and cycle time is inversely proportional to the number of operators—see [Manual MIG Welding Process Cycle Time](#).

Manual MIG Welding Process Cycle Time

$$\text{Cycle Time} = (\text{Labor Time} / \text{Number of Operators}) * \text{Cycle Time Adjustment Factor}$$

Cycle time depends on the following:

- Labor Time (see [Manual MIG Welding Accounting Calculations](#))
- Number of operators: specified by the machine property **Number of Operators**. Note that cycle time is inversely proportional to the number of operators.
- Cycle time adjustment factor: specified by the cost model variable **cycleTimeAdjustmentFactor**; 1 in aPriori starting point VPEs. If you want to model an unbalanced, push assembly line, set **cycleTimeAdjustmentFactor** to a value greater than 1 in order to account for the cost of extra buffer capacity.

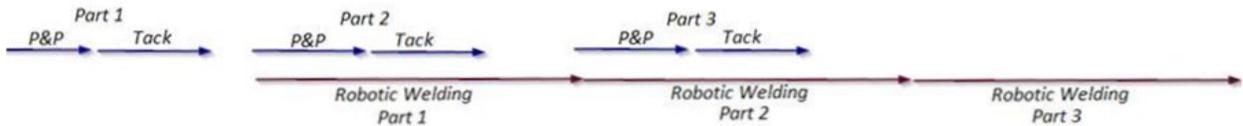
Note that indirect overhead depends on cycle time, while direct overhead depends on labor time. Cycle time contributes to part cost *only* via indirect overhead.

Robotic MIG Welding Labor Time

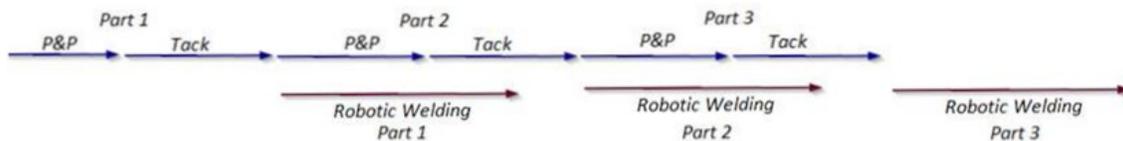
During the time the robot is welding one assembly, the operator (or operators or fraction of an operator) who tends the robotic welding machine is assumed to perform both the following tasks on the subsequent assembly:

- Pick and place (P&P in the diagram below)
- Manual tack welding (Tack in the diagram below)

Case 1



Case 2



Elapsed Time = max (
Pick And Place Labor Time + Operation Tack Times / Number of Operators,
Operation Weld Times / Number of Weld Heads)

Elapsed time for robotic welding is calculated based on two cases:

- Case 1: if tacking is completed before the robot finishes welding, elapsed time for this process is the elapsed time for the robot-performed welding (sum of the weld times on the child GCDs divided by the number of weld heads).
- Case 2: if tacking is completed after the robot finishes welding, elapsed time for this process is pick and place process time plus the elapsed time for tacking (sum of the tack times on the child GCDs divided by the number of operators).

Therefore, elapsed time depends on the following:

- Pick and place labor time (see [Pick and Place Accounting Calculations](#))
- Operation tack times (sum of the tack times for all child operations--see Tack Time formula in [MIG Welding Operation Weld Time](#))
- Number of operators: specified by the machine property **Number of Operators** or by the PSO **Number of operators tending to this machine**. This is the number of operators tending to the robotic welding machine, some or all of whom also do pick and place tasks.
- Operation weld times (sum of the weld times for all child operations--see Weld Time formula in [MIG Welding Operation Weld Time](#))
- Number of weld heads (specified by the machine property **Number of Weld Heads**)

Note that the cost model assumes that elapsed tack time is inversely proportional to the number of operators, and elapsed robot-performed weld time is inversely proportional to the number of weld heads.

Labor Time = (Elapsed Time * Number of Operators * Labor Time standard) – Pick And Place Labor Time

Labor time for robotic MIG welding is the labor time for a robotic MIG welding cycle that is over and above the time spent on pick and place. In other words, the labor time for robotic MIG welding is the difference between the following:

- Elapsed time (see below) for robotic MIG welding multiplied by the number of operators (and adjusted by labor time standard)
- Labor time for one pick and place cycle

Therefore, labor time depends on the following:

- Elapsed time (see formula)
- Number of operators: specified by the machine property **Number of Operators** or by the PSO **Number of operators tending to this machine**. This is the number of operators tending to the robotic welding machine, some or all of whom also do pick and place tasks.

The corresponding Pick and Place machine property or PSO (see [Process Cycle Time Calculation](#) and [Pick and Place Options](#)) specifies the total number of operators performing pick and place tasks, including any Robotic MIG Welding operators who perform pick and place tasks—see [Robotic MIG Welding Process-level Options](#) for more information.

- Labor time standard: specified as the machine property **Labor Time Standard**. This multiplier is used to account for otherwise unaccounted for factors that affect labor time, such as operator fatigue or time spent by the operator for cleaning or maintenance.
- Pick and place labor time (see [Pick and Place Accounting Calculations](#))

Robotic MIG Welding Accounting Calculations

Amortized Batch Setup = (Setup Time * (Labor Rate + Direct Overhead Rate)) / Batch Size

Amortized batch setup depends on the following:

- Setup time (specified as the machine property **Setup Time**)
- Labor rate (specified by the machine property **Labor Rate**)
- Direct overhead rate (see [Direct and Indirect Overhead](#))
- Batch size (specified in the **Production Scenario** screen of the Cost Guide)

Labor Cost = Labor Time * Labor Rate / Final Yield

Labor cost depends on the following:

- Labor time (see [Robotic MIG Welding Labor Time](#))
- Labor rate (specified by the machine property **Labor Rate**)
- Final yield (see [Yields](#))

MIG Welding Expendable Tooling Calculation

The formula in this section is used by both Manual and Robotic MIG Welding.

$$\text{Expendable Tooling Cost} = ((\text{Weld Weight} * \text{Wire Cost}) + \text{Antispatter Spray Cost} + \text{Nozzle Cost} + \text{Tip Cost}) / \text{Final Yield}$$

Expendable tooling cost accounts for the cost of the welding wire for the assembly. It depends on the following:

- Weld weight (see [MIG Welding Weld Weight](#))
- Wire cost (specified by the machine property **Wire Cost**)
- Antispatter spray cost: cost per unit mass for antispatter spray. This is the sum of the spray costs for all the assembly's welds. By default in starting point VPEs, the cost for a given weld is specified by the formula Antispatter Spray Cost (see below). Administrators can customize the default, and specify *no cost* for antispatter spray, by setting the cost model variable **weldAntiSpatterSprayEnabled** to **false**. Users can override the default on a per weld basis with the setup option [Enable Anti-Spatter Spray](#).
- Nozzle cost (see formula)
- Tip cost (see formula)
- Final yield (see [Yields](#))

$$\text{Antispatter Spray Cost} = \text{Antispatter Spray Mass Applied} * \text{Antispatter Spray Cost Per Unit Mass}$$

This is the cost of antispatter spray for a given weld, provided that the setup option [Enable Anti-Spatter Spray](#) is set to **true** (the cost is 0 otherwise). It depends on the following:

- Antispatter spray mass applied (see formula)
- Antispatter Spray Cost Per Unit Mass

$$\text{Antispatter Spray Cost Per Unit Mass} = (\text{Spray Cost} / (\text{Spray Volume} * \text{Spray Density}))$$

This is the cost per unit mass of antispatter spray for a given weld. It depends on the following:

- Spray cost: this is the **Spray Cost** of the lowest-**Spray-Cost** spray listed in the lookup table **tblWeldAntiSpatterSpray**. (Note that Spray Cost is *not* cost per unit mass or unit volume, but rather is cost per container.)

Spray Name	Spray Cost (USD)	Volume (mL)	Discharge Rate (g / s)	Relative Density (g / cm ³)	Spray Time Per Weld Length (s)
Ambersil	6.00	400.00	0.90	1.03	0.05
CRC	6.75	500.00	0.90	1.30	0.05
Rocol	15.71	300.00	0.90	1.10	0.05

- Spray volume: this is the **Volume** of one container of spray for the lowest-**Spray-Cost** spray listed in the lookup table **tblWeldAntiSpatterSpray**.
- Spray density: this is the **Density** of the lowest-**Spray-Cost** spray listed in the lookup table **tblWeldAntiSpatterSpray**.

$$\text{Antispatter Spray Mass Applied} = (\text{Weld Length} * \text{Spray Time Per Weld Length}) * \text{Spray Discharge Rate}$$

The mass of the antispatter spray applied to a given weld depends on the following:

- Weld length: specified by the user or imported from CAD.
- Spray time per weld length: this is the time per unit length to apply the spray. It is the **Spray Time Per Weld Length** for the lowest-**Spray-Cost** spray listed in the lookup table **tblWeldAntiSpatterSpray**.
- Spray discharge rate: this is the mass per unit time that is expended during spraying.

$$\text{Nozzle Cost} = (\text{Weld Weight} / \text{Weld Nozzle Replacement Rate}) * \text{Weld Nozzle Cost}$$

Nozzle cost depends on the following:

- Weld weight: total weld weight for all the assembly's welds--see [MIG Welding Weld Weight](#).
- Weld nozzle replacement rate: the mass of welding wire used per nozzle, specified by the cost model variable **weldNozzleReplacementRate**—18kg in starting point VPEs.
- Weld nozzle cost: cost per nozzle, specified by the cost model variable **weldNozzleCost**—13.57 U.S. dollars per nozzle in starting point VPEs.

$$\text{Tip Cost} = (\text{Weld Weight} / \text{Weld Tip Replacement Rate}) * \text{Weld Tip Cost}$$

Nozzle cost depends on the following:

- Weld weight: total weld weight for all the assembly's welds--see [MIG Welding Weld Weight](#).
- Weld tip replacement rate: the mass of welding wire used per nozzle, specified by the cost model variable **weldTipReplacementRate**—9kg in starting point VPEs.
- Weld nozzle cost: cost per nozzle, specified by the cost model variable **weldTipCost**—0.32 U.S. dollars per nozzle in starting point VPEs.

Additional Direct Costs for MIG Welding

Additional direct costs consist of the sum of the gas costs for all the assembly's welds:

$$\text{Gas Cost} = \text{Weld Time} * \text{Gas Cost Per Hour}$$

Gas cost is the product of the following:

- Weld time: this is the sum of all the operation-level weld times--see [MIG Welding Operation Weld Time](#)).
- Gas cost per hour: this is looked up by [Filler Material Type](#), [Travel Speed](#), and [Gas Type used for Welding](#) in the lookup table **tblWeldTravelSpeed**.

Note that weld time is converted to hours in this formula, since gas cost is per hour.

Manual TIG Welding and Robotic TIG Welding

This section has the following subsections:

- TIG Welding Operation Weld Time
- TIG Welding Weld Weight
- Manual TIG Welding Accounting Calculations
- Manual TIG Welding Process Cycle Time
- Robotic TIG Welding Labor Time
- Robotic TIG Welding Accounting Calculations
- TIG Welding Expendable Tooling Calculation
- Additional Direct Costs for TIG Welding

TIG Welding Operation Weld Time

The formulas in this section are used by the Welding operation for both Manual TIG Welding and Robotic TIG Welding.

Weld Time = Arc Time + Tack Time + Gun Manipulation Time + Gun Clean Time

For each Weld GCD, weld time is the sum of the following:

- Arc time (see formula)
- Tack time (see formula)
- Gun manipulation time (see formula)
- Gun clean time (see formula)

Arc Time

Arc time is the time for the arcing phase of welding—it excludes arc time for tack welding. Arc time is determined in one of two ways:

- Linear Rate Method: based on the following:
 - Weld length
 - Travel rate, derived from weld position (flat, overhead, or horizontal/vertical), [Weld Throat](#), and filler material type, or specified by the user
 - Number of passes, derived from [Weld Throat](#), or specified by the user
- Volumetric Rate Method: based on the following:
 - Weld volume
 - Deposition rate, derived from an estimate of wire diameter and the machine property **Wire Feed Rate**

The volume method is used by default in starting point VPEs. Administrators can customize the default (for both MIG and TIG welding) by setting the cost model variable **weldLinearFeedRate** to **true**. Users can override the default on a per-weld basis with the setup option [Weld Cycle Time Method](#).

See the formulas for **Volume Method Arc Time** and **Length Method Arc Time**, below.

Material	...	...	...	Throat Thickness (mm)	Position	...	Travel Speed (mm / s)
Aluminum	...	...	...	0.28	Flat	...	3.38
Aluminum	...	...	...	0.28	Flat	...	3.38
Aluminum	...	...	...	0.28	Flat	...	3.38
Aluminum	...	...	...	0.28	Horizontal & Vertical	...	3.10
Aluminum	...	...	...	0.28	Horizontal & Vertical	...	3.10
Aluminum	...	...	...	0.28	Horizontal & Vertical	...	3.10
Aluminum	...	...	...	0.28	Overhead	...	3.00
Aluminum	...	...	...	0.28	Overhead	...	3.00
Aluminum	...	...	...	0.28	Overhead	...	3.00
Aluminum	...	...	...	0.56	Flat	...	4.23
Aluminum	...	...	...	0.56	Flat	...	4.23
Aluminum	...	...	...	0.56	Flat	...	4.23
Aluminum	...	...	...	0.56	Horizontal & Vertical	...	4.00

- Arc time factor: this adjusts arc time according to weld type. It is looked up by weld type in the lookup table **tblWeldArcTimeFactor**.

Weld Type	Arc Time Factor
Bevel Groove	1.00
Fillet	1.00
Flared Bevel Groove	0.40
Flared V-Groove	0.60
J-Groove	1.50
Plug	1.00
Slot	1.00
Spot	1.00
Square Groove	2.00
Tack	1.00
U-Groove	1.70
V-Groove	1.00
Wrap Tie	1.00

Theoretical Arc time = GCD Volume / (Arc Efficiency * Deposition Rate)

Theoretical arc time depends on the following:

- GCD volume (based on geometry extraction or user-specified weld dimensions and weld type)
- Arc efficiency: fraction of welding wire that ends up in the weld and is not lost to spatter and evaporation. This value is specified by the cost model variable **arcEfficiency** (0.5 in starting point VPEs).
- Deposition rate (see formula)

Deposition rate = $\text{Pi} * (\text{Wire Diameter}^2 / 4) * \text{Wire Feed Rate}$

Deposition rate is the weld volume per unit time that is deposited during the arcing phase. It depends on the following:

- Wire diameter: this is looked up by travel speed, [Assembly Position](#), and [Assembly Material Type](#) in the lookup table [tblTigWelding](#). By default, travel speed is looked up by [Weld Throat](#), [Assembly Position](#), and [Assembly Material Type](#) in the lookup table [tblTigWelding](#). Users can override the default with the setup option [Travel Speed](#).
- Wire feed rate is the wire length per unit time that is deposited during the arcing phase (specified by the machine property [Wire Feed Rate](#))

Gun Manipulation Time = Number of Weld Segments * Gun Placement Time per Segment

Gun manipulation time includes all tasks between welds such as lifting the hood or visor, moving to the next location, repositioning the torch, readying to strike, and so forth. It is the product of the following:

- Number of weld segments (specified by the user or geometry extraction)
- Gun placement time per segment (specified by the machine property [Gun Placement Time](#))

Gun Clean Time = Arc Time * Gun Clean Time per Unit Arc Time

Gun clean time is the time for robotic cleaning of weld spatter from around the contact tip and nozzle. It is the product of the following:

- Arc time (see formula)
- Gun clean time per unit arc time (specified by the machine property [Gun Clean Time per Arc](#))

Operation Tack Time Calculations

Tack Time = Tack Arc Time + Tack Gun Manipulation Time + Tack Gun Clean Time

If tacking is enabled, tack time is the sum of the following:

- Tack arc time (see formula)
- Tack gun manipulation time (see formula)
- Tack gun clean time (see formula)

If tacking is not enabled tack time is 0.

For robotic welding, by default in starting point VPEs, operators are assumed to perform tack welding in order to prepare the workpieces. VPE administrators can customize the default with the cost model variable [enableTackingWithRoboticWelding](#). Users can override the default with the setup option [Enable Tacking Operation](#).

For manual welding, tacking is always assumed to be performed.

Tack Arc Time = Theoretical Tack Arc Time * Arc Time Standard

Tack arc time is the product of the following:

- Theoretical tack arc time (see formula)

- Arc time standard: multiplier to account for any operator pauses or breaks between cycles. Specified by the machine property **Arc Time Std**.

Theoretical Tack Arc Time = Tack Volume / Arc Efficiency * Deposition Rate

Theoretical tack arc time depends on the following:

- Tack volume (see formula for appropriate weld type)
- Arc efficiency: fraction of welding wire that ends up in the weld and is not lost to spatter and evaporation. This value is specified by the cost model variable **arcEfficiency** (0.5 in starting point VPEs).
- Deposition rate (see formula)

Tack Volume for Slot and Plug Welds = gcd.volume * tackLength / tackPitch

The cost model assumes that the cross-section area of a tack weld is the same as the cross-section area of the robot-created weld—they differ only in length. For slot and plug welds, it assumes that the ratio of tack volume to the volume of the robot-created weld is the same as the ratio of tack length to tack pitch. (Tack pitch is the distance from the start of one tack weld to the start of the next tack weld.)

Tack volume for slot and plug welds depends on the following:

- GCD volume (based on geometry extraction or user-specified weld dimensions and weld type)
- Tack length (specified by the machine property **Tack Length**)
- Tack pitch (specified by the machine property **Tack Pitch**)

Tack Volume for Non-slot, Non-plug Welds = Tack Cross-section Area * tackLength * numTacks

Tack volume for welds other than slot and plug welds is the product of the following:

- Tack cross-section area (see formula)
- Tack length. This is the length of a single tack weld, specified by the machine property **Tack Length**.
- Number of tacks (see formula)

Tack Cross-section Area = Weld Volume / Weld Length * Number of Weld Segments

Tack cross-section area is the area of a tack weld cross-section normal to the weld's length direction (the direction of motion of the gun during arcing). It depends on the following:

- Weld volume
- Weld length
- Number of weld segments

Number of Tacks for Slot and Plug Welds= Number of Weld Segments

For slot and plug welds, the number of tacks is the same as the number of weld segments specified by the user or determined by geometry extraction.

Number of Tacks for Non-slot, Non-plug Welds= Roundup(Arcing Length / Tack Pitch)

For non-slot, non-plug welds, the number of tacks is the minimum number of tack welds required to have a tack weld at the beginning and end of the weld GCD, with tack welds in between spaced by no more than tack pitch. Number of tacks is the quotient of the following, rounded *up* the nearest whole number:

- Arcing length (see formula)
- Tack pitch (specified by the machine property **Tack Pitch**)

Arcing Length = Segment Length * Number of Segments

Arcing length is the total distance the point of deposition travels during arcing phase for all weld segments. It is the product of the following:

- Segment length (specified by the user or determined by geometry extraction)
- Number of segments (specified by the user or determined by geometry extraction)

Tack Gun Manipulation Time = Number of Tacks * Gun Placement Time per Segment

For tacking, gun manipulation time is the product of the following:

- Number of tacks (see formula)
- Gun placement time per segment (specified by the machine property **Gun Placement Time**)

Tack Gun Clean Time = Tack Arc Time * Gun Clean Time per Unit Arc Time

Gun clean time is the time for robotic cleaning of weld spatter from around the contact tip and nozzle. The gun cleaning time associated with tacking is the product of the following:

- Tack arc time (see formula)
- Gun clean time per unit arc time (specified by the machine property **Gun Clean Time per Arc**)

TIG Welding Weld Weight

The formula in this section is used by both Manual and Robotic TIG Welding.

Weld Weight = GCD Volume * Weld Density

The weight of each weld GCD is used to calculate the total weld weight, which affects expendable tooling costs, as well as total assembly weight, which affects Pick and Place costs. The weight in kilograms of each weld GCD is the product of the following:

- GCD Volume (based on geometry extraction or user-specified weld dimensions and weld type)
- Weld density: specified in kg/m³ by the machine property **Weld Density**. aPriori converts this value to kg/mm³.

Manual TIG Welding Accounting Calculations

Amortized Batch Setup =

$$(\text{Setup Time} * (\text{Labor Rate} + \text{Direct Overhead Rate})) / \text{Batch Size}$$

Amortized batch setup depends on the following:

- Setup time (specified as the machine property **Setup Time**)
- Labor rate (specified by the machine property **Labor Rate**)
- Direct overhead rate (see [Direct and Indirect Overhead](#))
- Batch size (specified in the **Production Scenario** screen of the Cost Guide)

Labor Cost = Labor Time * Labor Rate / Final Yield

Labor cost depends on the following:

- Labor time (see formula)
- Labor rate (specified by the machine property **Labor Rate**)
- Final yield (see [Yields](#))

Labor Time = Operation Weld Times * Labor Time Standard

Labor time is the product of the following:

- Operation weld times: sum of the weld times and tack times of all child operations—see [TIG Welding Operation Weld Time](#).
- Labor time standard: specified as the machine property **Labor Time Standard**. This multiplier is used to account for otherwise unaccounted for factors that affect labor time, such as operator fatigue or time spent by the operator for cleaning or maintenance.

Note that labor time is independent of the number of operators, and cycle time is inversely proportional to the number of operators—see [Manual TIG Welding Process Cycle Time](#).

Manual TIG Welding Process Cycle Time

Cycle Time = (Labor Time / Number of Operators) * Cycle Time Adjustment Factor

Cycle time depends on the following:

- Labor Time (see [Manual TIG Welding Accounting Calculations](#))
- Number of operators: specified by the machine property **Number of Operators**. Note that cycle time is inversely proportional to the number of operators. Increasing the number of operators is assumed to speed up the welding cycle.
- Cycle time adjustment factor: specified by the cost model variable **cycleTimeAdjustmentFactor**; 1 in aPiori starting point VPEs. If you want to model an unbalanced, push assembly line, set **cycleTimeAdjustmentFactor** to a value greater than 1 in order to account for the cost of extra buffer capacity.

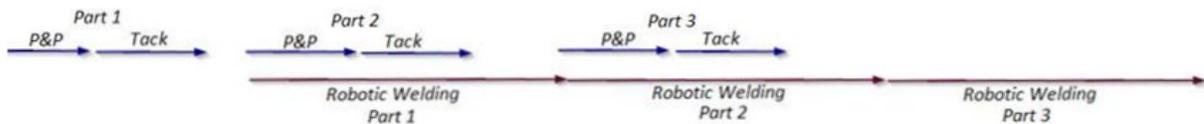
Note that indirect overhead depends on cycle time, while direct overhead depends on labor time. Cycle time contributes to part cost *only* via indirect overhead.

Robotic TIG Welding Labor Time

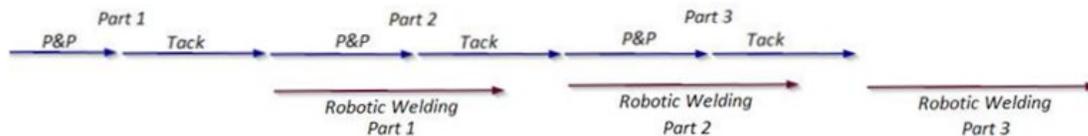
During the time the robot is welding one assembly, the operator (or operators or fraction of an operator) who tends the robotic welding machine is assumed to perform both the following tasks on the subsequent assembly:

- Pick and place (P&P in the diagram below)
- Manual tack welding (Tack in the diagram below)

Case 1



Case 2



Elapsed Time = max (
Pick And Place Labor Time + Operation Tack Times / Number of Operators,
Operation Weld Times / Number of Weld Heads)

Elapsed time for robotic welding is calculated based on two cases:

- If tacking is completed before the robot finishes welding, elapsed time for this process is the elapsed time for the robot-performed welding (sum of the weld times on the child GCDs divided by the number of weld heads).
- If tacking is completed after the robot finishes welding, elapsed time for this process is pick and place process time plus the elapsed time for tacking (sum of the tack times on the child GCDs divided by the number of operators).

Therefore, elapsed time depends on the following:

- Pick and place labor time (see [Pick and Place Accounting Calculations](#))
- Operation tack times (sum of the tack times for all child operations--see Tack Time formula in [TIG Welding Operation Weld Time](#))
- Number of operators: specified by the machine property **Number of Operators** or by the PSO **Number of operators tending to this machine**. This is the number of operators tending to the robotic welding machine, some or all of whom also do pick and place tasks.
- Operation weld times (sum of the weld times for all child operations--see Weld Time formula in [TIG Welding Operation Weld Time](#))
- Number of weld heads (specified by the machine property **Number of Weld Heads**)

Note that the cost model assumes that elapsed tack time is inversely proportional to the number of operators, and elapsed robot-performed weld time is inversely proportional to the number of weld heads.

Labor Time = (Elapsed Time * Number of Operators * Labor Time standard) – Pick And Place Labor Time

Labor time for robotic TIG welding is the labor time for a robotic TIG welding cycle that is over and above the time spent on pick and place. In other words, the labor time for robotic TIG welding is the difference between the following:

- Elapsed time (see below) for robotic TIG welding multiplied by the number of operators (and adjusted by labor time standard)
- Labor time for one pick and place cycle

Therefore, labor time depends on the following:

- Elapsed time (see formula)
- Number of operators: specified by the machine property **Number of Operators** or by the PSO **Number of operators tending to this machine**. This is the number of operators tending to the robotic welding machine, some or all of whom also do pick and place tasks.

The corresponding Pick and Place machine property or PSO (see [Process Cycle Time Calculation](#) and [Pick and Place Options](#)) specifies the total number of operators performing pick and place tasks, including any Robotic TIG Welding operators who perform pick and place tasks—see [Number of Operators](#) for more information.

- Labor time standard: specified as the machine property **Labor Time Standard**. This multiplier is used to account for otherwise unaccounted for factors that affect labor time, such as operator fatigue or time spent by the operator for cleaning or maintenance.
- Pick and place labor time (see [Pick and Place Accounting Calculations](#))

Robotic TIG Welding Accounting Calculations

Amortized Batch Setup = (Setup Time * (Labor Rate + Direct Overhead Rate)) / Batch Size

Amortized batch setup depends on the following:

- Setup time (specified as the machine property **Setup Time**)
- Labor rate (specified by the machine property **Labor Rate**)
- Direct overhead rate (see [Direct and Indirect Overhead](#))
- Batch size (specified in the **Production Scenario** screen of the Cost Guide)

Labor Cost = Labor Time * Labor Rate / Final Yield

Labor cost depends on the following:

- Labor time (see [Robotic TIG Welding Labor Time](#))
- Labor rate (specified by the machine property **Labor Rate**)
- Final yield (see [Yields](#))

TIG Welding Expendable Tooling Calculation

The formulas in this section are used by both Manual and Robotic TIG Welding.

$$\text{Expendable Tooling Cost} = ((\text{Weld Weight} * \text{Wire Cost}) + \text{Antispatter Spray Cost} + \text{Nozzle Cost} + \text{Tip Cost}) / \text{Final Yield}$$

Expendable tooling cost accounts for the cost of the welding wire for the assembly. It depends on the following:

- Weld weight (see [TIG Welding Weld Weight](#))
- Wire cost (specified by the machine property **Wire Cost**)
- Antispatter spray cost: cost per unit mass for antispatter spray. This is the sum of the spray costs for all the assembly's welds. By default in starting point VPEs, the cost for a given weld is specified by the formula Antispatter Spray Cost (see below). Administrators can customize the default, and specify *no cost* for antispatter spray, by setting the cost model variable **weldAntiSpatterSprayEnabled** to **false**. Users can override the default on a per weld basis with the setup option .
- Nozzle cost (see formula)
- Tip cost (see formula)
- Final yield (see [Yields](#))

$$\text{Antispatter Spray Cost} = \text{Antispatter Spray Mass Applied} * \text{Antispatter Spray Cost Per Unit Mass}$$

This is the cost of antispatter spray for a given weld, provided that the setup option [Enable Anti-Spatter Spray](#) is set to **true** (the cost is 0 otherwise). It depends on the following:

- Antispatter spray mass applied (see formula)
- Antispatter Spray Cost Per Unit Mass

$$\text{Antispatter Spray Cost Per Unit Mass} = (\text{Spray Cost} / (\text{Spray Volume} * \text{Spray Density}))$$

This is the cost per unit mass of antispatter spray for a given weld. It depends on the following:

- Spray cost: this is the **Spray Cost** of the lowest-**Spray-Cost** spray listed in the lookup table **tblWeldAntiSpatterSpray**. (Note that Spray Cost is *not* cost per unit mass or unit volume, but rather is cost per container.)

Spray Name	Spray Cost (USD)	Volume (mL)	Discharge Rate (g / s)	Relative Density (g / cm ³)	Spray Time Per Weld Length (s)
Ambersil	6.00	400.00	0.90	1.03	0.05
CRC	6.75	500.00	0.90	1.30	0.05
Rocol	15.71	300.00	0.90	1.10	0.05

- Spray volume: this is the **Volume** of one container of spray for the lowest-**Spray-Cost** spray listed in the lookup table **tblWeldAntiSpatterSpray**.
- Spray density: this is the **Density** of the lowest-**Spray-Cost** spray listed in the lookup table **tblWeldAntiSpatterSpray**.

$$\text{Antispatter Spray Mass Applied} = (\text{Weld Length} * \text{Spray Time Per Weld Length}) * \text{Spray Discharge Rate}$$

The mass of the antispatter spray applied to a given weld depends on the following:

- Weld length: specified by the user or imported from CAD.
- Spray time per weld length: this is the time per unit length to apply the spray. It is the **Spray Time Per Weld Length** for the lowest-**Spray-Cost** spray listed in the lookup table **tblWeldAntiSpatterSpray**.
- Spray discharge rate: this is the mass per unit time that is expended during spraying.

$$\text{Nozzle Cost} = (\text{Weld Weight} / \text{Weld Nozzle Replacement Rate}) * \text{Weld Nozzle Cost}$$

Nozzle cost depends on the following:

- Weld weight: total weld weight for all the assembly's welds--see [TIG Welding Weld Weight](#).
- Weld nozzle replacement rate: the mass of welding wire used per nozzle, specified by the cost model variable **weldNozzleReplacementRate**—18kg in starting point VPEs.
- Weld nozzle cost: cost per nozzle, specified by the cost model variable **weldNozzleCost**—13.57 U.S. dollars per nozzle in starting point VPEs.

$$\text{Tip Cost} = (\text{Weld Weight} / \text{Weld Tip Replacement Rate}) * \text{Weld Tip Cost}$$

Nozzle cost depends on the following:

- Weld weight: total weld weight for all the assembly's welds--see [TIG Welding Weld Weight](#).
- Weld tip replacement rate: the mass of welding wire used per nozzle, specified by the cost model variable **weldTipReplacementRate**—9kg in starting point VPEs.
- Weld nozzle cost: cost per nozzle, specified by the cost model variable **weldTipCost**—0.32 U.S. dollars per nozzle in starting point VPEs.

Additional Direct Costs for TIG Welding

Additional direct costs consist of the sum of the gas costs for all the assembly's welds:

$$\text{Gas Cost} = \text{Weld Time} * \text{Gas Cost Per Hour}$$

Gas cost is the product of the following:

- Weld time: this is the sum of all the operation-level weld times--see [TIG Welding Operation Weld Time](#)).
- Gas cost per hour: this is looked up by [Assembly Material Type](#), [Travel Speed](#), and [Gas Type used for Welding](#) in the lookup table **tblTigWelding**.

Note that weld time is converted to hours in this formula, since gas cost is per hour.

Manual Spot Welding and Robotic Spot Welding

Spot Welding Operation Cycle Time

Cycle time for the weld operation is the time it takes to create the weld represented by the current GCD.

Weld Time = Arc Time + Gun Manipulation Time

For each Weld GCD, weld time is the sum of the following:

- Arc time (see formula)
- Gun manipulation time (see formula)
- Gun clean time (see formula)

Arc Time = Number of Weld Segments * Spot Weld Time

Arc time is the time for the arcing phase of welding. It is the product of the following:

- Number of weld segments (extracted from the CAD model or specified by the user in the Welding dialog)
- Spot weld time (specified by the machine property **Spot Weld Time**)

Gun Manipulation Time = Number of Weld Segments * Gun Placement Time per Segment

Gun manipulation time includes all tasks between welds such as lifting the hood or visor, moving to the next location, repositioning the torch, readying to strike, and so forth. It is the product of the following:

- Number of weld segments (specified by the user or geometry extraction)
- Gun placement time per segment (specified by the machine property **Gun Placement Time**)

Spot Welding Weld Weight

Weld Weight = GCD Volume * Weld Density

The weight of each weld GCD is used to calculate the total assembly weight, which affects expendable tooling costs for Welding, as well as Pick and Place costs. The weight in kilograms of each weld GCD is the product of the following:

- GCD Volume (based on geometry extraction or user-specified weld dimensions and weld type)
- Weld density: specified in kg/m³ by the machine property **Weld Density**. aPriori converts this value to kg/mm³.

Spot Welding Accounting Calculations

Amortized Batch Setup =

$$(\text{Setup Time} * (\text{Labor Rate} + \text{Direct Overhead Rate})) / \text{Batch Size}$$

This is the per-part cost of setting up one production batch of parts, that is, the batch setup cost amortized over all the parts in the batch. It depends on the following:

- Setup time (specified as the machine property **Setup Time**)
- Labor rate (specified by the machine property **Labor Rate**)

- Direct overhead rate (see [Direct and Indirect Overhead](#))
- Batch size (specified in the **Production Scenario** screen of the Cost Guide)

Labor Cost = Labor Time * Labor Rate / Final Yield

Labor cost depends on the following:

- Labor time (see formula)
- Labor rate (specified by the machine property **Labor Rate**)
- Final yield (see [Yields](#))

Robotic Spot Welding Labor Time = (Operation Weld Times / Number of Weld Heads) *

Number of Operators * Labor Time Standard

Labor time is the product of the following:

- Operation weld times: sum of the weld times of all child operations—see [Spot Welding Operation Cycle Time](#).
- Number of weld heads: specified by the machine property **Number of Weld Heads**.
- Number of operators: specified by the machine property **Number of Operators** or by the PSO **Number of operators tending to this machine**.
- Labor time standard: specified as the machine property **Labor Time Standard**. This multiplier is used to account for otherwise unaccounted for factors that affect labor time, such as operator fatigue or time spent by the operator for cleaning or maintenance.

Manual Spot Welding Labor Time = Operation Weld Times * Labor Time Standard

Labor time is the product of the following:

- Operation weld times: sum of the weld times of all child operations—see [Spot Welding Operation Cycle Time](#).
- Labor time standard: specified as the machine property **Labor Time Standard**. This multiplier is used to account for otherwise unaccounted for factors that affect labor time, such as operator fatigue or time spent by the operator for cleaning or maintenance.

Note that for Manual Spot Welding, labor time is independent of the number of operators, and cycle time is assumed to be inversely proportional to the number of operators (see [Manual Spot Welding Process Cycle Time](#)).

Robotic Spot Welding Process Cycle Time

Cycle Time = (Operation Weld Times / Number of Weld Heads) * Cycle Time Adjustment Factor

Cycle time depends on the following:

- Operation weld times: sum of the weld times of all child operations—see [Spot Welding Operation Cycle Time](#).
- Number of weld heads: specified by the machine property **Number of Weld Heads**.
- Cycle time adjustment factor: specified by the cost model variable **cycleTimeAdjustmentFactor**; 1 in aPriori starting point VPEs. If you want to model an

unbalanced, push assembly line, set **cycleTimeAdjustmentFactor** to a value greater than 1 in order to account for the cost of extra buffer capacity.

Note that indirect overhead depends on cycle time, while direct overhead depends on labor time. Cycle time contributes to part cost *only* via indirect overhead.

Manual Spot Welding Process Cycle Time

Cycle Time = (Labor Time / Number of Operators) * Cycle Time Adjustment Factor

Cycle time depends on the following:

- Labor time (see Manual Spot Welding Labor Time in [Spot Welding Accounting Calculations](#)).
- Number of operators: specified by the machine property Number of Operators. Note that cycle time is inversely proportional to the number of operators.
- Cycle time adjustment factor: specified by the cost model variable **cycleTimeAdjustmentFactor**; 1 in aPiori starting point VPEs. If you want to model an unbalanced, push assembly line, set **cycleTimeAdjustmentFactor** to a value greater than 1 in order to account for the cost of extra buffer capacity.

Note that indirect overhead depends on cycle time, while direct overhead depends on labor time. Cycle time contributes to part cost *only* via indirect overhead.

Spot Welding Expendable Tooling Calculation

Expendable Tooling Cost = Weld Weight *Wire Cost per Unit / Final Yield

Expendable tooling cost accounts for the cost of the welding wire for assembly. It depends on the following:

- Weld Weight (see [Spot Welding Weld Weight](#))
- Wire cost per unit mass (specified by the machine property **Wire Cost**)
- Final yield (see [Yields](#))

Electron Beam Welding Formulas

The process time calculation for Electron Beam Welding uses the following formulas:

- Process Time
- Per-GCD Weld Time

Process Time

Some electron beam welding (EBW) machines have multiple workstations, allowing operators to load and unload parts from one workstation while parts at another workstation are robotically welded. Such machines allow for two parallel streams of activity:

- Load/Unload Stream: includes *loading and unloading* of parts.
- Welding Stream: includes *welding* all the parts' welds.

Each of these streams can also include other auxiliary activities. Which other activities are included, if any, depends on the type of EBW machine involved. There are two types of multi-station EBW machines:

- Cycle machines: have a rotating table that moves parts between a load/unload station and a welding chamber.
- Load lock machines: have two chambers, so welding can be performed in one chamber while pumping (to create a vacuum in the chamber) or venting (to eliminate the vacuum) is performed in the other chamber.

The machine properties **Is Cycle Machine** and **Is Load Lock Machine** indicate machine type. If both these properties are **false** for a given machine, the machine is assumed to be a standard machine, with a single station.

With cycle machines, the welding activity stream includes the pumping and venting activities:

- Load/Unload Stream: *loading and unloading*
- Welding Stream: *welding, pumping, and venting*

With load lock machines, the loading/unloading activity stream also includes pumping and venting:

- Load/Unload Stream: *loading, unloading, pumping, and venting*
- Welding Stream: *welding*

Therefore, with two-chamber machines, process time for a given batch of parts is the duration of the stream that takes the longest, plus the duration of activities related to moving parts between stations (which cannot be performed in parallel with other activities). These activities include the following:

- *cycle machine*, for cycle machines: this is the table rotation required for moving parts between stations.
- *load lock*, for load lock machines: this is the shuttle and transfer involved in moving parts between stations.

With single-station machines, all activities are performed in sequence:

Single Chamber Process Time =

Load Time + Pump Time + Weld Time + Vent Time + Unload Time

Load lock machines use this formula:

Load Lock Machine Process Time = Longest Event Stream Time + Load Lock Time

Cycle machines use this formula:

Cycle Machine Process Time = Longest Event Stream Time + Cycle Machine Time

Note that these are per-batch process times. Per-part process times are per-batch times divided by the [Number of Parts in the Machine per Cycle](#).

These formulas rely on the following values:

- Load time: By default, load time per part is looked up by part weight in the lookup table **componentLoadTime**.

Load Time (s)	Weight (kg)
0.00	0.00
1.00	0.05
5.00	0.20
8.00	1.00
11.00	5.00
17.00	20.00
25.00	27.00
80.00	999,999,999.00

This value is multiplied by the **Number of Parts in the Machine per Cycle**.

Users can override the default load time with the setup option **Time to Load the Assembly**.

- Unload time: as with load time, by default, per-part unload time is looked up by part weight in the lookup table **componentLoadTime**. This value is multiplied by the **Number of Parts in the Machine per Cycle**.
Users can override the default load time with the setup option **Time to Unload the Assembly**.
- Pump time: specified by the machine property **Pump Time**.
- Vent time: specified by the machine property **Vent Time**.
- Weld time: Sum of the weld times for each of the part's Weld GCDs, multiplied by the **Number of Parts in the Machine per Cycle**. See **Per-GCD Weld Time**.
- Load lock time: specified by the machine property **Load Lock Time**.
- Cycle machine time: specified by the machine property **Cycle Machine Time**.

Per-GCD Weld Time

Weld time for a single Weld GCD is given by the formulas below.

$$\text{Weld Time} = (\text{Weld Length} * \text{Number of Weld Segments} / \text{Weld Speed}) + \text{Part Manipulation Time}$$

Weld time depends on the following:

- Weld length (specified by the user or geometry extraction)
- Number of weld segments (specified by the user or geometry extraction)
- Weld speed (see formula)
- Part manipulation time: this is the product of the number of weld segments and the machine property **Part Placement Time**.

Weld Speed =

$$(\text{Power Factor} * \text{Machine Power} / (\text{Weld Depth} + \text{Depth Factor}))^{\text{Speed Factor}}$$

Default weld speed depends on the following:

- Power factor: specified by the cost model variable **EBWPowerFactor** (5 in starting point VPEs).
- Machine power: specified by the machine property **Machine Power**.
- Weld depth (specified by the user or geometry extraction)
- Depth factor: specified by the cost model variable **EBWDepthFactor** (0.25 in starting point VPEs).
- Speed factor: specified by the cost model variable **EBWSpeedFactor** (1.5 in starting point VPEs).

The speed is bounded above by the machine property **Max Speed**.

Users can override the default speed with the setup option **Weld Speed**.

Laser Welding Formulas

The process time calculation for Electron Beam Welding uses the following formulas:

$$\text{Process Time} = (\text{Weld Time} + \text{Load Time} + \text{Unload Time}) / \text{Number of Weld Heads}$$

Process time depends on the following:

- Weld Time (see formula)
- Load time: per-part load time. By default, this is looked up by part weight in the lookup table **componentLoadTime**:

Load Time (s)	Weight (kg)
0.00	0.00
1.00	0.05
5.00	0.20
8.00	1.00
11.00	5.00
17.00	20.00
25.00	27.00
80.00	999,999,999.00

Users can override the calculated load time for the entire batch (see **Number of Parts in the Machine per Cycle**) with the setup option **Time to Load the Assembly**.

- Unload time: per-part unload time. This is looked up by part weight in the lookup table **componentLoadTime**. Users can override the calculated load time for the entire batch (see **Number of Parts in the Machine per Cycle**) with the setup option **Time to Unload the Assembly**.
- Number of weld heads: specified by the machine property **Number of Heads**.

Per-GCD Weld Time

Weld time for a single Weld GCD is given by the formulas below.

Weld Time = (Weld Length * Number of Weld Segments / Weld Speed) + Part Manipulation Time

Weld time depends on the following:

- Weld length (specified by the user or geometry extraction)
- Number of weld segments (specified by the user or geometry extraction)
- Weld speed (see formula)
- Part manipulation time: this is the product of the number of weld segments and the machine property **Part Placement Time**.

Weld Speed = ((Efficiency Factor * Machine Power) / Weld Depth)

Default weld speed depends on the following:

- Efficiency factor: specified by the cost model variable **LWEfficiencyFactor** (20 in starting point VPEs).
- Machine power: specified by the machine property **Machine Power**.
- Weld depth (specified by the user or geometry extraction)

The speed is bounded above by the machine property **Max Speed**.

Users can override the default speed with the setup option **Weld Speed**.

Pick and Place Formulas

Assembly Weight

Assembly Weight = Component Weight + Weld Weight

Assembly weight affects process and operation cycle times. It is the sum of the following:

- Component weight: sum of the weights of the assembly's components
- Weld weight: sum of the weights of the assembly's welds (see [MIG Welding Weld Weight](#), [TIG Welding Weld Weight](#), and [Spot Welding Weld Weight](#))

Clamp Operation Cycle Time Calculation

Cycle time for this operation is the time to clamp the part in the fixture for subsequent operations. It is determined in one of the following ways:

- Specified by the PSO **Clamping Time**.
- Looked up by assembly weight (see [Assembly Weight](#)) in the lookup table **xtraLoadTime**.

Load Operation Cycle Time Calculation

Cycle Time = Base Load Time * Additional Handling Factor * Difficult Insertion Factor

Cycle time for the Load operation is the time to load the part into the assembly fixture or to a mating part already assembled, including bin pick and insertion time. It is the product of the following:

- Base load time: specified by the PSO **Base Load Time** or looked up by assembly weight (see [Assembly Weight](#)) in the lookup table **componentLoadTime**.
- Additional handling factor: accounts for handling difficulties such as nesting, stickiness, fragility, and so forth. The factor is 1 by default, or specified by the PSO **Load time multiplier for handling difficulties**.
- Difficult Insertion Factor: accounts for difficulties with alignment and positioning due to either obstructed access or vision, or lack of alignment features such as chamfers and lead-ins. The factor is 1 by default, or specified by the PSO **Load time multiplier for insertion difficulties**.

Reorient Operation Cycle Time Calculation

Cycle time for the Reorient operation is determined in one of the following ways:

- Specified by the cost model variable **reorientTime** (9 seconds in aPriori starting point VPEs).
- Specified by the PSO **ReOrient - Turn Assembly Over**.

Pick and Place Accounting Calculations

Labor Cost = Labor Time * Labor Rate / Final Yield

Labor cost depends on the following:

- Labor time (see formula)
- Labor rate (specified by the machine property **Labor Rate**)
- Final yield (see [Yields](#))

Labor Time = Process Time * Labor Time Standard

Labor time is the product of the following:

- Process time (see formula)
- Labor time standard: specified as the machine property **Labor Time Standard**. This multiplier is used to account for otherwise unaccounted for factors that affect labor time, such as operator fatigue or time spent by the operator for cleaning or maintenance.

Process Time = Operation Cycle Times + Unload Assembly Fixture Time

Process time is the sum of the following:

- Operation cycle times: sum of the cycle times of all child operations—see [Clamp Operation Cycle Time Calculation](#), [Load Operation Cycle Time Calculation](#), and [Reorient Operation Cycle Time Calculation](#).
- Unload assembly fixture time: time to unload the finished assembly at the end of the assembly process. This is specified by the PSO **Time to Unload the Assembly**

Fixture or looked up by component weight (sum of the weights of the assembly's components) in the lookup table **unloadWeldmentAllowance**.

**Amortized Batch Setup =
(Setup Time * (Labor Rate + Direct Overhead Rate)) / Batch Size**

Amortized batch setup is the cost per part for setting up one production batch for the current process. Starting point VPEs assume that there is *no* batch setup associated with the Pick and Place process, but VPE administrators can configure the cost model to include setup cost (by setting the machine property **Setup Time** to a nonzero value).

Setup cost depends on the following:

- Setup time (specified as the machine property **Setup Time**)
- Labor rate (specified by the machine property **Labor Rate**)
- Direct overhead rate (see [Direct and Indirect Overhead](#))
- Batch size (specified in the **Production Scenario** screen of the Cost Guide)

Process Cycle Time Calculation

Cycle time for the whole process is given by the following formula:

Cycle Time = (Labor Time / Number of Operators) * Cycle Time Adjustment Factor

Cycle time depends on the following:

- Labor time (see [Pick and Place Accounting Calculations](#))
- Number of operators: specified by the machine property **Number of Operators** or by the PSO **Number of Operators**. Note that cycle time is assumed to be inversely proportional to the number of operators.

This is the total number of operators performing pick and place tasks, including any Robotic Welding operators who perform pick and place tasks—see [Robotic MIG Welding Process-level Options](#) and [Robotic TIG Welding Process-level Options](#) for more information.

- Cycle time adjustment factor: specified by the cost model variable **cycleTimeAdjustmentFactor**; 1 in aPriori starting point VPEs. If you want to model an unbalanced, push assembly line, set **cycleTimeAdjustmentFactor** to a value greater than 1 in order to account for the cost of extra buffer capacity.

Note that indirect overhead depends on cycle time, while direct overhead depends on labor time. Cycle time contributes to part cost *only* via indirect overhead.

Weld Prep Calculations

Bevel Cutting Operation Cycle Time

Cycle Time = Pierce Time + Cut Time

Cycle time is the sum of the following:

- Pierce time: looked up by weld depth in the lookup table **bevelCutInfo**. Weld depth is determined by geometry extraction or (for virtual welds) specified by the user in the Welding dialog when the weld was created.
- Cut time (see formula)

Cut Time = Weld Length / Cut Speed * Number of Cuts

Cut time depends on the following:

- Weld length: determined by geometry extraction or (for virtual welds) specified by the user in the Welding dialog when the weld was created.
- Cut speed: looked up by weld depth in the lookup table **bevelCutInfo**. The table value is in millimeters per minute; it is converted to millimeters per second in order to calculate cut time. Weld depth is determined by geometry extraction or (for virtual welds) specified in the Welding dialog when the weld was created.
- Number of cuts: depends on the weld type as specified by the geometric property Type. Number of cuts is 2 for the following types:
 - V-Groove
 - U-Groove
 - Flared V-Groove

Number of cuts is 1 for all other types.

Grinding Operation Cycle Time

Cycle Time = Weld Length * Number of Passes / Grinding Speed

Cycle time depends on the following:

- Weld length: determined by geometry extraction or (for virtual welds) specified by the user in the Welding dialog when the weld was created.
- Number of passes: 2
- Grinding speed: specified by the machine property **Grinding Speed**.

Wire Brushing Operation Cycle Time

Cycle Time = Weld Length * Number of Passes / Wire Brushing Speed

Cycle time depends on the following:

- Weld length: determined by geometry extraction or (for virtual welds) specified by the user in the Welding dialog when the weld was created.
- Number of passes: 2
- Wire brushing speed: specified by the machine property **Wire Brushing Speed**.

Weld Prep Process Accounting

Labor Time = Operation Cycle Times * Labor Time Standard

Labor time is the product of the following:

- Operation cycle times is sum of the cycle times of all child operations for all subcomponents.
- Labor time standard: specified as the machine property **Labor Time Standard**. This multiplier is used to account for otherwise unaccounted for factors that affect labor time, such as operator fatigue or time spent by the operator for cleaning or maintenance.

Labor Cost = Labor Time * Labor Rate / Final Yield

Labor cost depends on the following:

- Labor time (see formula)
- Labor rate (specified by the machine property **Labor Rate**)
- Final yield (see [Yields](#))

Amortized Batch Setup = (Setup Time * (Labor Rate + Direct Overhead Rate)) / Batch Size

Amortized batch setup depends on the following:

- Setup time (specified as the machine property **Setup Time**)
- Labor rate (specified by the machine property **Labor Rate**)
- Direct overhead rate (see [Direct and Indirect Overhead](#))

Weld Prep process Cycle Time

Cycle Time = (Labor Time / Number of Operators) * Cycle Time Adjustment Factor

- Labor time (see [Weld Prep Process Accounting](#))
- Number of operators: specified by the machine property **Number of Operators**.
- Cycle time adjustment factor: specified by the cost model variable **cycleTimeAdjustmentFactor**; 1 in aPriori starting point VPEs. If you want to model an unbalanced, push assembly line, set **cycleTimeAdjustmentFactor** to a value greater than 1 in order to account for the cost of extra buffer capacity.

Note that indirect overhead depends on cycle time, while direct overhead depends on labor time. Cycle time contributes to part cost *only* via indirect overhead.

Weld Clean Up Calculations

Grinding Operation Cycle Time

Cycle Time = Weld Length / Grinding Speed

Cycle time depends on the following:

- Weld length: determined by geometry extraction or (for virtual welds) specified by the user in the Welding dialog when the weld was created.
- Grinding speed: specified by the machine property **Grinding Speed**.

Weld Clean Up Process Accounting

Labor Time = Operation Cycle Times * Labor Time Standard

Labor time is the product of the following:

- Operation cycle times is sum of the cycle times of all child operations for all subcomponents.
- Labor time standard: specified as the machine property **Labor Time Standard**. This multiplier is used to account for otherwise unaccounted for factors that affect

labor time, such as operator fatigue or time spent by the operator for cleaning or maintenance.

Labor Cost = Labor Time * Labor Rate / Final Yield

Labor cost depends on the following:

- Labor time (see formula)
- Labor rate (specified by the machine property **Labor Rate**)
- Final yield (see [Yields](#))

Amortized Batch Setup = (Setup Time * (Labor Rate + Direct Overhead Rate)) / Batch Size

Amortized batch setup depends on the following:

- Setup time (specified as the machine property **Setup Time**)
- Labor rate (specified by the machine property **Labor Rate**)
- Direct overhead rate (see [Direct and Indirect Overhead](#))

Weld Clean Up process Cycle Time

Cycle Time = (Labor Time / Number of Operators) * Cycle Time Adjustment Factor

- Labor time (see [Weld Clean Up Process Accounting](#))
- Number of operators: specified by the machine property **Number of Operators**.
- Cycle time adjustment factor: specified by the cost model variable **cycleTimeAdjustmentFactor**; 1 in aPiori starting point VPEs. If you want to model an unbalanced, push assembly line, set **cycleTimeAdjustmentFactor** to a value greater than 1 in order to account for the cost of extra buffer capacity.

Note that indirect overhead depends on cycle time, while direct overhead depends on labor time. Cycle time contributes to part cost *only* via indirect overhead.

Mechanical Assembly Calculations

Nut Insert Operation Cycle Time

Cycle Time = Standard Nut Insert Time + Additional Time

Time to insert a nut is the sum of the following:

- Standard nut insert time: this is looked up by the current process and operation in the lookup table **tblMechanicalOperationTimes** (1.5 seconds in aPiori starting point VPEs).
- Additional time: this is 0 by default. Users can specify additional time with the operation-specific or GCD-specific PSO **Nut Insert Obstructed Or Vision**. The time added is looked up by the current process, operation, and PSO setting in the lookup table **tblMechanicalOperationTimes**.

Process	Operation	Operation Time (s)	Blind Or Obstructed Time (s)	Blind And Obstructed Time (s)
Lock Bolt	Bolt Placement	3.00	2.50	4.00
Lock Bolt	Collar Placement	2.00	2.50	4.00
Mechanical Assembly	Nut Insert	1.50	2.50	4.00
Mechanical Assembly	Press Fit	7.50	2.50	4.00
Mechanical Assembly	Rivet	8.00	2.50	4.00
Mechanical Assembly	Screw Tighten - Manual	12.00	5.00	8.00
Mechanical Assembly	Screw Tighten - Power	6.00	2.50	4.00
Mechanical Assembly	Snap Fit	3.00	2.50	4.00
Mechanical Assembly	Tab Bend	3.50	2.50	4.00
Threaded Insert	Tang Break	1.00	2.50	4.00
Threaded Insert	Threaded Insert Op	1.00	2.50	4.00

Press Fit Operation Cycle Time

Cycle Time = Standard Press Fit Time + Additional Time

Cycle time is the sum of the following:

- Standard press fit time: by default, this is looked up by the current process and operation in the lookup table **tblMechanicalOperationTimes** (7.5 seconds in aPriori starting point VPEs).
- Additional time: this is 0 by default. Users can specify additional time with the operation-specific or GCD-specific PSO **Press Fit Obstructed Or Vision**. The time added is looked up by the current process, operation, and PSO setting in the lookup table **tblMechanicalOperationTimes**.

Rivet Operation Cycle Time

Cycle Time = Standard Rivet Time + Additional Time

Cycle time is the sum of the following:

- Standard rivet time: by default, this is looked up by the current process and operation in the lookup table **tblMechanicalOperationTimes** (8 seconds in aPriori starting point VPEs).
- Additional time: this is 0 by default. Users can specify additional time with the operation-specific or GCD-specific PSO **Rivet Obstructed Or Vision**. The time added is looked up by the current process, operation, and PSO setting in the lookup table **tblMechanicalOperationTimes**.

Screw Tighten - Manual Operation Cycle Time

Cycle Time = Standard Manual Screw Tightening Time + Additional Time

Cycle time is the sum of the following:

- Standard manual screw tightening time: by default, this is looked up by the current process and operation in the lookup table **tblMechanicalOperationTimes** (12 seconds in aPriori starting point VPEs).
- Additional time: this is 0 by default. Users can specify additional time with the operation-specific or GCD-specific PSO **Screw Tighten - Manual Obstructed Or**

Vision. The time added is looked up by the current process, operation, and PSO setting in the lookup table **tblMechanicalOperationTimes**.

Screw Tighten - Power Operation Cycle Time

Cycle Time = Standard Power Screw Tightening Time + Additional Time

Cycle time is the sum of the following:

- Standard power screw tightening time: by default, this is looked up by the current process and operation in the lookup table **tblMechanicalOperationTimes** (6 seconds in aPriori starting point VPEs).
- Additional time: this is 0 by default. Users can specify additional time with the operation-specific or GCD-specific PSO **Screw Tighten - Power Obstructed Or Vision**. The time added is looked up by the current process, operation, and PSO setting in the lookup table **tblMechanicalOperationTimes**.

Snap Fit Operation Cycle Time

Cycle Time = Standard Snap Time + Additional Time

Cycle time is the sum of the following:

- Standard snap fit time: by default, this is looked up by the current process and operation in the lookup table **tblMechanicalOperationTimes** (3 seconds in aPriori starting point VPEs).
- Additional time: this is 0 by default. Users can specify additional time with the operation-specific or GCD-specific PSO **Snap Fit Obstructed Or Vision**. The time added is looked up by the current process, operation, and PSO setting in the lookup table **tblMechanicalOperationTimes**.

Tab Bend Operation Cycle Time

Cycle Time = Tab Bend Time + Additional Time

Cycle time is the sum of the following:

- Standard tab bend time: by default, this is looked up by the current process and operation in the lookup table **tblMechanicalOperationTimes** (3.5 seconds in aPriori starting point VPEs).
- Additional time: this is 0 by default. Users can specify additional time with the operation-specific or GCD-specific PSO **Tab Bend Obstructed Or Vision**. The time added is looked up by the current process, operation, and PSO setting in the lookup table **tblMechanicalOperationTimes**.

Mechanical Assembly Accounting calculations

Labor Time = Operation Cycle Times * Labor Time Standard

Labor time is the product of the following:

- Operation cycle times is sum of the cycle times of all child operations for all subcomponents.
- Labor time standard: specified as the machine property **Labor Time Standard**. This multiplier is used to account for otherwise unaccounted for factors that affect

labor time, such as operator fatigue or time spent by the operator for cleaning or maintenance.

Labor Cost = Labor Time * Labor Rate / Final Yield

Labor cost depends on the following:

- Labor time (see formula)
- Labor rate (specified by the machine property **Labor Rate**)
- Final yield (see [Yields](#))

Amortized Batch Setup = (Setup Time * (Labor Rate + Direct Overhead Rate)) / Batch Size

Amortized batch setup depends on the following:

- Setup time (specified as the machine property **Setup Time**)
- Labor rate (specified by the machine property **Labor Rate**)
- Direct overhead rate (see [Direct and Indirect Overhead](#))

Mechanical Assembly Process Cycle Time

Cycle Time = (Labor Time / Number of Operators) * Cycle Time Adjustment Factor

- Operation cycle times is sum of the cycle times of all child operations for all subcomponents.
- Number of operators: specified by the machine property **Number of Operators**.
- Cycle time adjustment factor: specified by the cost model variable **cycleTimeAdjustmentFactor**; 1 in aPriori starting point VPEs. If you want to model an unbalanced, push assembly line, set **cycleTimeAdjustmentFactor** to a value greater than 1 in order to account for the cost of extra buffer capacity.

Note that indirect overhead depends on cycle time, while direct overhead depends on labor time. Cycle time contributes to part cost *only* via indirect overhead.

User Inputs

This section covers process setup options (PSOs). It has the following subsections:

- [Adhesive Bonding Options](#)
- [Lock Bolt Options](#)
- For [Lock Bolt](#) and [Threaded Insert](#) setup options, the lookup table **tblProcessSetupOptionSelection** lists the possible settings. The entry with 1 in the priority column provides the default for all setup options.
- [Threaded Insert Options](#)
- [Cap Sealing Options](#)
- [Fay Sealing Options](#)
- [Fillet Sealing Options](#)
- [Rivet Process Options](#)

- Pick and Place Options
- Robotic MIG Welding Process-level Options
- MIG Welding GCD-level Options
- Robotic TIG Welding Process-level Options
- TIG Welding GCD-level Options
- Robotic Spot Welding Options
- Electron Beam Welding Options
- Laser Welding Options
- Mechanical Assembly Options

Adhesive Bonding Options

Adhesive Bonding provides the following setup options:

- Adhesive Resin Type
- Bonded Area

Adhesive Resin Type

This specifies the type of adhesive to use, which affects costs for [Expendable Tooling for Adhesive Bonding](#).

By default in starting point VPEs, the adhesive type is **Acrylic**. Administrators can customize the default with the cost model variable **defaultAdhesiveResin**. With this setup option, users can override the default on a per-part basis, and specify one of the resin types listed in the lookup table **adhesiveResins**.

Adhesive Type	Cost Per Kg (USD / kg)
Acrylic	105.28
Epoxy	461.00
Urethane	444.40

Bonded Area

This setup option specifies the percentage of the total assembly surface area to which adhesive is applied. This value plays a role in [Cycle Time Formulas for Adhesive Bonding](#) as well as in calculations for [Expendable Tooling for Adhesive Bonding](#).

In starting point VPEs, the default portion of total surface area to be bonded is 10%. Administrators can customize the default by using the cost model variable **defaultPercentBonded**. Users can override the default on a per-part basis with this setup option.

Lock Bolt Options

The Lock Bolt Install operation provides the following options:

- Lock Bolt Obstructed Or Vision
- Lock Bolt Collar and Hand Tool Obstructed or Blind

Lock Bolt provides the following options:

Lock Bolt Obstructed Or Vision

Specifies whether there is an obstruction or vision problem that adds to the time required to place the bolt (see [Lock Bolt Formulas](#)). The default setting in starting point VPEs is **No obstructed access or vision problem**. You can override the default and specify one of the following options:

- **Obstructed access OR vision problems** (adds 2.5 seconds in aPriori starting point VPEs)
- **Obstructed access AND vision problems** (adds 4 seconds in aPriori starting point VPEs)

The time added is looked up by the current process, task, and PSO setting in the lookup table **tblMechanicalOperationTimes**. See [Lock Bolt Formulas](#).

Process	Operation	Operation Time (s)	Blind Or Obstructed Time (s)	Blind And Obstructed Time (s)
Lock Bolt	Bolt Placement	3.00	2.50	4.00
Lock Bolt	Collar Placement	2.00	2.50	4.00
Mechanical Assembly	Nut Insert	1.50	2.50	4.00
Mechanical Assembly	Press Fit	7.50	2.50	4.00
Mechanical Assembly	Rivet	8.00	2.50	4.00
Mechanical Assembly	Screw Tighten - Manual	12.00	5.00	8.00
Mechanical Assembly	Screw Tighten - Power	6.00	2.50	4.00
Mechanical Assembly	Snap Fit	3.00	2.50	4.00
Mechanical Assembly	Tab Bend	3.50	2.50	4.00
Threaded Insert	Tang Break	1.00	2.50	4.00
Threaded Insert	Threaded Insert Op	1.00	2.50	4.00

For both this setup option and [Lock Bolt Collar and Hand Tool Obstructed or Blind](#), the lookup table **tblProcessSetupOptionSelection** lists the possible settings; the entry with 1 in the priority column provides the default for both setup options.

PSO Reference Key	Selection Name	Priority
mechOpObstructSelection	No obstructed access or vision problem	1.00
mechOpObstructSelection	Obstructed access AND vision problems	3.00
mechOpObstructSelection	Obstructed access OR vision problems	2.00

Lock Bolt Collar and Hand Tool Obstructed or Blind

Specifies whether there is an obstruction or vision problem that adds to the time required to place the collar and position a hand tool (see [Lock Bolt Formulas](#)). The default setting

in starting point VPEs is **No obstructed access or vision problem**. You can override the default and specify one of the following:

- **Obstructed access OR vision problems** (adds 2.5 seconds in aPriori starting point VPEs)
- **Obstructed access AND vision problems** (adds 4 seconds in aPriori starting point VPEs)

The time added is looked up by the current process, task, and PSO setting in the lookup table **tblMechanicalOperationTimes**. See [Lock Bolt Formulas](#).

Note that the time is added to *both* the time to place the collar and the time to tighten it. (Any obstruction and/or vision problem indicated by this option is assumed to apply to both the placement and the tightening task, since both tasks involve access to the relevant portion of the assembly from the same direction.)

For Lock Bolt and Threaded Insert setup options, the lookup table **tblProcessSetupOptionSelection** lists the possible settings. The entry with 1 in the priority column provides the default for all setup options.

Threaded Insert Options

The Threaded Insert operation provides the following options:

- [Threaded Insert Obstructed Or Vision](#)
- [Tang Break Obstructed Or Vision](#)

Threaded Insert Obstructed Or Vision

Specifies whether there is an obstruction or vision problem that adds to the time required to insert the threaded insert (see [Threaded Insert Formulas](#)). The default setting in starting point VPEs is **No obstructed access or vision problem**. You can override the default and specify one of the following:

- **Obstructed access OR vision problems** (adds 2.5 seconds in aPriori starting point VPEs)
- **Obstructed access AND vision problems** (adds 4 seconds in aPriori starting point VPEs)

The time added is looked up by the current process, task, and PSO setting in the lookup table **tblMechanicalOperationTimes**. See [Threaded Insert Formulas](#).

Process	Operation	Operation Time (s)	Blind Or Obstructed Time (s)	Blind And Obstructed Time (s)
Lock Bolt	Bolt Placement	3.00	2.50	4.00
Lock Bolt	Collar Placement	2.00	2.50	4.00
Mechanical Assembly	Nut Insert	1.50	2.50	4.00
Mechanical Assembly	Press Fit	7.50	2.50	4.00
Mechanical Assembly	Rivet	8.00	2.50	4.00
Mechanical Assembly	Screw Tighten - Manual	12.00	5.00	8.00
Mechanical Assembly	Screw Tighten - Power	6.00	2.50	4.00
Mechanical Assembly	Snap Fit	3.00	2.50	4.00
Mechanical Assembly	Tab Bend	3.50	2.50	4.00
Threaded Insert	Tang Break	1.00	2.50	4.00
Threaded Insert	Threaded Insert Op	1.00	2.50	4.00

For Lock Bolt and Threaded Insert setup options, the lookup table **tblProcessSetupOptionSelection** lists the possible settings. The entry with 1 in the **priority** column provides the default for all setup options.

PSO Reference Key	Selection Name	Priority
mechOpObstructSelection	No obstructed access or vision problem	1.00
mechOpObstructSelection	Obstructed access AND vision problems	3.00
mechOpObstructSelection	Obstructed access OR vision problems	2.00

Tang Break Obstructed Or Vision

Specifies whether there is an obstruction or vision problem that adds to the time required to break the tang (**Threaded Insert Formulas**). The default setting in starting point VPEs is **No obstructed access or vision problem**. You can override the default and specify one of the following:

- **Obstructed access OR vision problems** (adds 2.5 seconds in aPriori starting point VPEs)
- **Obstructed access AND vision problems** (adds 4 seconds in aPriori starting point VPEs)

The time added is looked up by the current process, task, and PSO setting in the lookup table **tblMechanicalOperationTimes**. See **Threaded Insert Formulas**.

For Lock Bolt and Threaded Insert setup options, the lookup table **tblProcessSetupOptionSelection** lists the possible settings. The entry with 1 in the **priority** column provides the default for all setup options.

Cap Sealing Options

The Cap Sealing process provides the following options:

- Number of Holes Cap Sealed
- Sealant Type

- Sealant Price
- Time to Cap Seal One Hole

Number of Holes Cap Sealed

By default, the number of cap-sealed holes is the sum of the following:

- Number of cap-sealed simple holes: this is the number of SimpleHole GCDs whose diameter is within range (see below).
- Number of cap-sealed complex holes: this is the number of ComplexHole GCDs whose MEC diameter (diameter of the largest circle that fits inside the hole) is in range.

A diameter or MEC diameter is in range if it is between the values of the following cost model variables:

- **minRivetDiameter** (2mm in starting point VPEs)
- **maxRivetDiameter** (8mm in starting point VPEs)

With this setup option, users can override the default number of cap-sealed holes.

The number of cap-sealed holes drives cycle time--see [Cap Sealing Formulas](#).

Sealant Type

By default, sealant type is specified by the cost model variable **defaultSealantType** (B2 Corrosion Inhibitant in starting point VPEs). With this setup option, users can override the default, and select from the sealant types listed in the lookup table **sealant**.

aP <i>sealant</i> ✕	
Cost Per KG (USD / kg)	Sealant Type
120.74	A2 Fuel Tank Sealant
127.54	B2 Corrosion Inhibitant
184.74	A1 Corrosion Inhibitant
189.40	C24 Fuel Tank Sealant

Sealant type determines **Sealant Price**, by default, which drives costs for sealant material—see Additional Direct Costs in [Cap Sealing Formulas](#).

Sealant Price

By default, sealant price is looked up by **Sealant Type** in the lookup table **sealant**. With this setup option, users can override the default.

aP <i>sealant</i> ✕	
Cost Per KG (USD / kg)	Sealant Type
120.74	A2 Fuel Tank Sealant
127.54	B2 Corrosion Inhibitant
184.74	A1 Corrosion Inhibitant
189.40	C24 Fuel Tank Sealant

Sealant price drives costs for sealant material—see Additional Direct Costs in [Cap Sealing Formulas](#).

Time to Cap Seal One Hole

By default, the time to seal one hole is specified by the cost model variable **defaultSealTime** (5 seconds, in starting point VPEs). With this setup option, users can override the default. This value drives cycle time—see [Cap Sealing Formulas](#).

Fay Sealing Options

The Fay Sealing process provides the following options:

- Bonded Area
- Sealant Price
- Sealant Type

Bonded Area

This is the fraction of the total assembly surface area to be bonded. By default, this is specified by the cost model variable **defaultPercentBonded** (10% in starting point VPEs). Users can override the default with this setup option. Bonded area drives cycle time and expendable tooling costs—see [Fay Sealing Formulas](#).

Sealant Price

By default, sealant price is looked up by [Sealant Type](#) in the lookup table **sealant**. With this setup option, users can override the default.

aP <i>sealant</i> ✕	
Cost Per KG (USD / kg)	Sealant Type
120.74	A2 Fuel Tank Sealant
127.54	B2 Corrosion Inhibitant
184.74	A1 Corrosion Inhibitant
189.40	C24 Fuel Tank Sealant

Sealant price drives costs for sealant material—see Expendable Tooling Costs in [Fay Sealing Formulas](#).

Sealant Type

By default, sealant type is specified by the cost model variable **defaultSealantType** (B2 Corrosion Inhibitant in starting point VPEs). With this setup option, users can override the default, and select from the sealant types listed in the lookup table **sealant**.

aP <i>sealant</i> ✕	
Cost Per KG (USD / kg)	Sealant Type
120.74	A2 Fuel Tank Sealant
127.54	B2 Corrosion Inhibitant
184.74	A1 Corrosion Inhibitant
189.40	C24 Fuel Tank Sealant

Sealant type determines [Sealant Price](#), by default, which drives costs for sealant material—see [Expendable Tooling Costs in Fillet Sealing Formulas](#).

Fillet Sealing Options

The Fillet Sealing process provides the following options:

- Sealant Type
- Sealant Price
- Time to Seal per Length
- Length of Sealant Required

Sealant Type

By default, sealant type is specified by the cost model variable **defaultSealantType** (B2 Corrosion Inhibitant in starting point VPEs). With this setup option, users can override the default, and select from the sealant types listed in the lookup table **sealant**.

Cost Per KG (USD / kg)	Sealant Type
120.74	A2 Fuel Tank Sealant
127.54	B2 Corrosion Inhibitant
184.74	A1 Corrosion Inhibitant
189.40	C24 Fuel Tank Sealant

Sealant type determines [Sealant Price](#), by default, which drives costs for sealant material—see [Additional Direct Costs in Fillet Sealing Formulas](#).

Sealant Price

By default, sealant price is looked up by [Sealant Type](#) in the lookup table **sealant**. With this setup option, users can override the default.

Cost Per KG (USD / kg)	Sealant Type
120.74	A2 Fuel Tank Sealant
127.54	B2 Corrosion Inhibitant
184.74	A1 Corrosion Inhibitant
189.40	C24 Fuel Tank Sealant

Sealant price drives costs for sealant material—see [Additional Direct Costs in Fillet Sealing Formulas](#).

Time to Seal per Length

This is the time per unit length required to apply the sealant (in seconds per millimeter). By default, it is specified by the machine property **Application Rate**. Users can override the default with this setup option. This value drives cycle time—see [Fillet Sealing Formulas](#).

Length of Sealant Required

This is the total length of sealant to be applied. By default, this is assumed to be a certain fraction of the sum of the subcomponent perimeters (where each subcomponent's perimeter is twice the sum of its length and width). The fraction is specified by the cost model variable **sealantFactor** (0.1 in starting point VPEs). Users can override the default with this setup option.

This value drives cycle time and additional direct costs—see [Fillet Sealing Formulas](#).

Rivet Process Options

The Rivet Process provides the following options:

- Riveted Hole Count
- Rivet Obstructed Or Vision

Riveted Hole Count

By default, the number of riveted holes is the sum of the following:

- Number of riveted simple holes: this is the number of SimpleHole GCDs whose diameter is within range (see below).
- Number of riveted complex holes: this is the number of ComplexHole GCDs whose MEC diameter (diameter of the largest circle that fits inside the hole) is in range.

A diameter or MEC diameter is in range if it is between the values of the following cost model variables:

- **minRivetDiameter** (2mm in starting point VPEs)
- **maxRivetDiameter** (8mm in starting point VPEs)

With this setup option, users can override the default number of riveted holes.

The number of riveted holes drives cycle time--see [Rivet Process Formulas](#).

Rivet Obstructed Or Vision

Specifies whether there is an obstruction or vision problem that adds to the time required to rivet holes (see [Rivet Process Formulas](#)). The default setting in starting point VPEs is **No obstructed access or vision problem**. You can override the default and specify one of the following options:

- **Obstructed access OR vision problems** (adds 2.5 seconds in aPriori starting point VPEs)
- **Obstructed access AND vision problems** (adds 4 seconds in aPriori starting point VPEs)

The time added is looked up by the current process group, process, and PSO setting in the lookup table **tblMechanicalOperationTimes**. See [Rivet Process Formulas](#).

Process	Operation	Operation Time (s)	Blind Or Obstructed Time (s)	Blind And Obstructed Time (s)
Assembly	Rivet	8.00	2.50	4.00
Assembly	Riveting	8.00	2.50	4.00
Lock Bolt	Bolt Placement	3.00	2.50	4.00
Lock Bolt	Collar Placement	2.00	2.50	4.00
Mechanical Assembly	Nut Insert	1.50	2.50	4.00
Mechanical Assembly	Press Fit	7.50	2.50	4.00
Mechanical Assembly	Rivet	8.00	2.50	4.00
Mechanical Assembly	Screw Tighten - Manual	12.00	5.00	8.00
Mechanical Assembly	Screw Tighten - Power	6.00	2.50	4.00
Mechanical Assembly	Snap Fit	3.00	2.50	4.00
Mechanical Assembly	Tab Bend	3.50	2.50	4.00
Threaded Insert	Tang Break	1.00	2.50	4.00
Threaded Insert	Threaded Insert Op	1.00	2.50	4.00

For both this setup option, the lookup table **tblProcessSetupOptionSelection** lists the possible settings; the entry with 1 in the priority column provides the default for both setup options.

PSO Reference Key	Selection Name	Priority
mechOpObstructSelection	No obstructed access or vision problem	1.00
mechOpObstructSelection	Obstructed access AND vision problems	3.00
mechOpObstructSelection	Obstructed access OR vision problems	2.00

Pick and Place Options

Process-level Options

The Pick and Place process provides the following options:

- **Time to Unload the Assembly Fixture:** time to unload the finished assembly at the end of the assembly process. By default this is looked up by component weight (sum of the weights of the assembly's components) in the lookup table **unloadWeldmentAllowance**. You can override the default and specify the time explicitly. This value contributes to cycle time (see [Process Cycle Time Calculation](#)). Select one of the following options:
 - **Use weight based computed value:** this is the default.
 - **User override value for this part:** enter a value greater than or equal to 0.
- **Number of Operators:** by default this is the value of the machine property **Number of Operators**. You can override the default and specify a different number of operators, including a fractional number of operators.

Note that labor time is independent of number of operators (see [Pick and Place Accounting Calculations](#)), and cycle time is inversely proportional to the number of operators (see [Process Cycle Time Calculation](#)).

This PSO specifies the total number of operators performing pick and place tasks, including any Robotic MIG Welding operators who perform pick and place tasks--see [Robotic MIG Welding Process-level Options](#) for more information.

Select one of the following options:

- **Default number of operators:** the value of the machine property Number of Operators (1 in aPriori starting point VPEs)
- **User override value for this part:** enter a value greater than or equal to 0.

Operation-level Options

You can specify per-subcomponent values with the options listed below.

The Clamp operation provides the following option:

- **Clamping Time:** time to clamp the part in the fixture for subsequent operations. By default this is looked up by assembly weight (see [Assembly Weight](#)) in the lookup table `xtraLoadTime` (see [Clamp Operation Cycle Time Calculation](#)). You can override the default and specify a time explicitly. Select one of the following options:
 - **Computed clamping time:** This is the default.
 - **User override clamp time for this part:** enter a numeric value.

The Load operation provides the following options:

- **Base Load Time:** contributes to [Load Operation Cycle Time Calculation](#). By default this is looked up by assembly weight (see [Assembly Weight](#)) in the lookup table `componentLoadTime`. You can override the default and specify the time explicitly. Select one of the following options:
 - **Computed base load time:** this is the default.
 - **User override base load time for this part:** enter a numeric value.
- **Load time multiplier for handling difficulties:** factor to account for additional time for handling difficulties such as nesting, stickiness, fragility, and so forth. It contributes to [Load Operation Cycle Time Calculation](#). By default this factor is 1. You can override the default with this PSO. Select one of the following:
 - **No additional time for handling difficulties:** this is the default.
 - **Standard handling difficulties multiplier:** use the value of the cost model variable `handlingMultiplier` (1.15 in aPriori starting point VPEs).
 - **User override multiplier for this part:** enter a numeric value.
- **Load time multiplier for insertion difficulties:** factor to account for additional time for difficulties with alignment and positioning, due to obstructed access or vision, or lack of alignment features such as chamfers and lead-ins. It contributes to [Load Operation Cycle Time Calculation](#). By default this factor is 1. You can override the default with this PSO. Select one of the following:
 - **No additional time for insertion difficulties:** this is the default.
 - **Standard insertion difficulties multiplier:** use the value of the cost model variable `insertionMultiplier` (1.2 in aPriori starting point VPEs).
- **User override multiplier for this part:** enter a numeric value.

The Reorient operation provides the following options:

- **ReOrient - Turn Assembly Over:** contributes to [Reorient Operation Cycle Time Calculation](#). By default this is the value of the cost model variable `reorientTime` (9 seconds in aPriori starting point VPEs). You can override the default and specify the time explicitly. Select one of the following options:
 - **Standard time:** this is the default.
 - **User override base load time for this part:** enter a numeric value.

Robotic MIG Welding Process-level Options

The Robotic MIG Welding process provides the following options:

- [Enable Tacking](#)
- [Number of Operators](#)

Enable Tacking

By default in starting point VPEs, operators are assumed to perform tack welding in order to prepare the workpieces. VPE administrators can customize the default with the cost model variable `enableTackingWithRoboticWelding` (`true` in starting point VPEs). Users can override the default with this setup option. See the formula [Tack Time in MIG Welding Operation Weld Time](#).

Number of Operators

Robotic MIG Welding provides an option that allows you to specify the number of operators tending to the robotic welder.

- **Number of operators tending to this machine:** By default this is the value of the machine property Number of Operators (1 in aPriori starting point VPEs). You can override the default and specify a different number of operators, including a fractional number of operators.

Note that at least some of the welding operators are assumed to perform pick and place tasks--see [Robotic MIG Welding](#) .

The corresponding Pick and Place machine property or PSO (see [Process Cycle Time Calculation](#) and [Pick and Place Options](#)) specifies the *total* number of operators performing pick and place tasks, including any Robotic MIG Welding operators who perform pick and place tasks.

Select one of the following options

- **Default number of operators:** specified by the machine property **Number of Operators**.
- **User override value for this part:** enter a value greater than or equal to 0.

MIG Welding GCD-level Options

The MIG Welding operation provides the following options, which can be set on a per-GCD basis:

- Weld Cycle Time Method
- Filler Material Type
- Travel Speed
- Number of Welding Passes
- Gas Type used for Welding
- Enable Anti-Spatter Spray

Weld Cycle Time Method

Welding arc time (see the formula for **Weld Time** in **MIG Welding Operation Weld Time**) is determined in one of two ways:

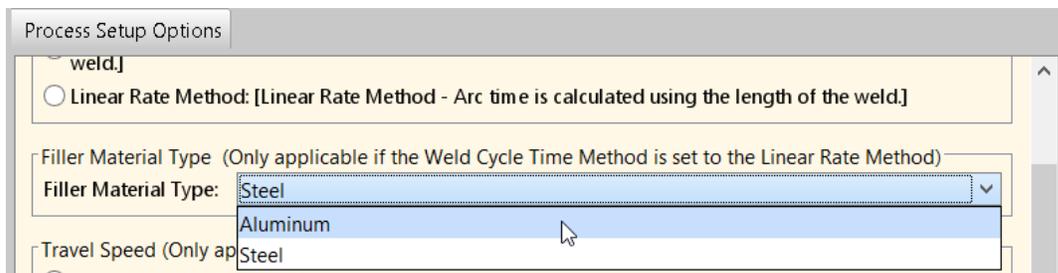
- Volumetric Rate Method: based on the following:
 - Weld volume
 - Deposition rate (derived from the machine properties **Wire Feed Rate** and **Wire Diameter**)
- Linear Rate Method: based on the following:
 - Weld length
 - **Travel Speed** (derived from **Weld Throat** and **Filler Material Type**, or specified by the user)
 - **Number of Welding Passes** (derived from weld volume and **Weld Throat**, or specified by the user)

The linear rate method is used by default in starting point VPEs. Administrators can customize the default (for both MIG and TIG welding) by setting the cost model variable **weldLinearFeedRate** to **false**. Users can override the default with this setup option.

See the formulas for **Volume Method Arc Time** and **Length Method Arc Time** in **MIG Welding Operation Weld Time**.

Filler Material Type

By default in starting point VPEs, the weld is assumed to use Steel filler. Administrators can customize the default with the cost model variable **defaultMigWeldingMaterialType**. Users can override the default filler type on a part-by-part basis with this setup option. Select from the dropdown list, (which is populated from the **Material Type** column of the lookup table **tblWeldTravelSpeed**).



Filler material type affects travel speed, which affects [MIG Welding Operation Weld Time](#) for the [Linear Rate Weld Cycle Time Method](#). It also affects [MIG Welding Weld Weight](#) and the [MIG Welding Expendable Tooling Calculation](#).

Travel Speed

If the linear rate [Weld Cycle Time Method](#) is used, weld time is based, in part, on travel speed. By default, travel speed is derived from [Weld Throat](#) and [Filler Material Type](#)—see [MIG Welding Operation Weld Time](#). Users can override the default on a part-by-part basis with this setup option.

Number of Welding Passes

If the linear rate [Weld Cycle Time Method](#) is used, weld time is based, in part, on the number of welding passes used for weld (that is, the number of times the weld head traverses the length of the weld). By default, the number of passes is derived from [Weld Throat](#)—see [MIG Welding Operation Weld Time](#). Users can override the default on a part-by-part basis with this setup option.

Gas Type used for Welding

By default, the type of gas used for welding is specified by the cost model variable [defaultMigWeldingGasType](#) (Argon in starting point VPEs). Users can override the default with this setup option. Gas type affects gas cost—see [Additional Direct Costs for MIG Welding](#).

Enable Anti-Spatter Spray

By default in starting point VPEs, costs for antispatter spray are included in expendable tooling costs—see [MIG Welding Expendable Tooling Calculation](#). Administrators can customize the default, and specify *no cost* for antisplatter spray, by setting the cost model variable [weldAntiSpatterSprayEnabled](#) to **false**. Users can override the default on a per weld basis with this setup option.

Robotic TIG Welding Process-level Options

The Robotic TIG Welding process provides the following options:

- [Enable Tacking Operation](#)
- [Number of Operators](#)

Enable Tacking Operation

By default in starting point VPEs, operators are assumed to perform tack welding in order to prepare the workpieces. VPE administrators can customize the default with the cost model variable [enableTackingWithRoboticWelding](#) (**true** in starting point VPEs). Users can override the default with this setup option. See the formula [Tack Time](#) in [TIG Welding Operation Weld Time](#).

Number of Operators

Robotic TIG Welding provides an option that allows you to specify the number of operators tending to the robotic welder.

- **Number of operators tending to this machine:** By default this is the value of the machine property Number of Operators (1 in aPriori starting point VPEs). You can override the default and specify a different number of operators, including a fractional number of operators.

Note that at least some of the welding operators are assumed to perform pick and place tasks--see [Robotic TIG Welding Labor Time](#).

Select one of the following options

- **Default number of operators:** specified by the machine property **Number of Operators**.
- **User override value for this part:** enter a value greater than or equal to 0.

TIG Welding GCD-level Options

The MIG Welding operation provides the following options, which can be set on a per-GCD basis:

- Weld Cycle Time Method
- Assembly Material Type
- Assembly Position
- Travel Speed
- Number of Welding Passes
- Gas Type used for Welding
- Enable Anti-Spatter Spray

Weld Cycle Time Method

Welding arc time (see the formula for **Weld Time** in [TIG Welding Operation Weld Time](#)) is determined in one of two ways:

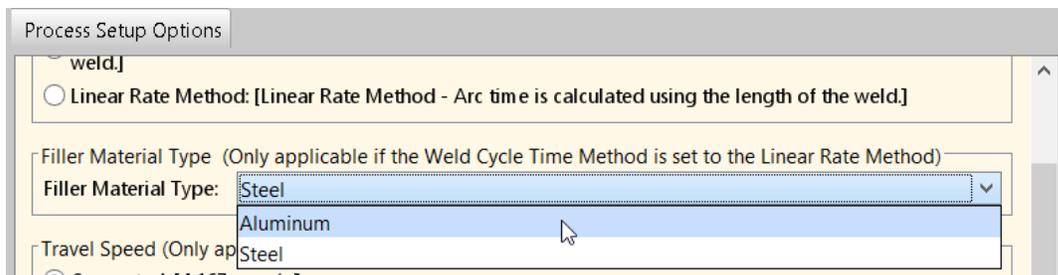
- Volumetric Rate Method: based on the following:
 - Weld volume
 - Deposition rate (derived from the machine property **Wire Feed Rate** and an estimate of wire diameter)
- Linear Rate Method: based on the following:
 - Weld length
 - **Travel Speed**, derived from **Weld Throat**, **Assembly Position**, and **Assembly Material Type**, or specified by the user
 - **Number of Welding Passes**, derived from **Weld Throat**, or specified by the user

The volume method is used by default in starting point VPEs. Administrators can customize the default (for both MIG and TIG welding) by setting the cost model variable **weldLinearFeedRate** to **true**. Users can override the default with this setup option.

See the formulas for **Volume Method Arc Time** and **Length Method Arc Time** in [TIG Welding Operation Weld Time](#).

Assembly Material Type

By default in starting point VPEs, the weld is assumed to use Steel filler. Administrators can customize the default with the cost model variable **defaultTigWeldingMaterialType**. Users can override the default filler type on a part-by-part basis with this setup option. Select from the dropdown list, (which is populated from the **Material Type** column of the lookup table **tblTigWelding**).



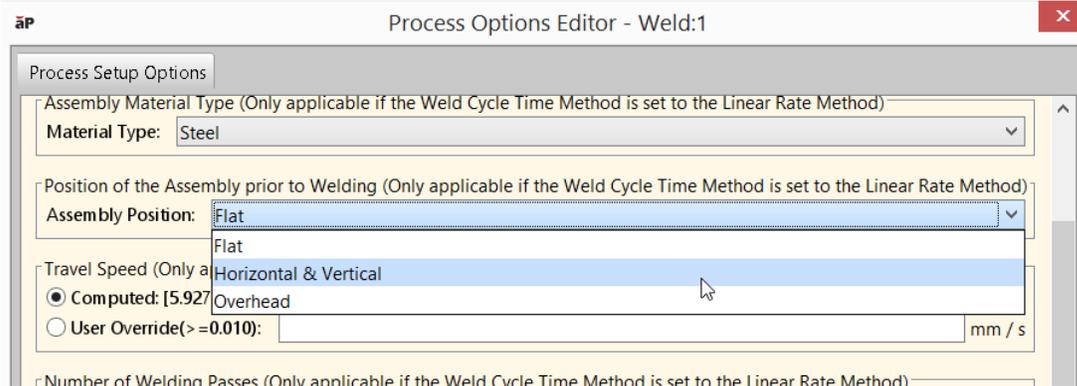
Filler material type affects travel speed, which affects [TIG Welding Operation Weld Time](#), if the [Linear Rate Weld Cycle Time Method](#) is enabled. It also affects [TIG Welding Weld Weight](#) and the [TIG Welding Expendable Tooling Calculation](#).

Assembly Position

This specifies the position of the assembly during welding:

- Flat: the weld head is held above the weld.
- Horizontal/vertical: the weld head is held at the same height as the weld.
- Overhead: the weld head is held below the weld.

By default in starting point VPEs, the assembly position is assumed to be Flat. Users can override the default position on a part-by-part basis with this setup option. Select from the dropdown list, (which is populated from the **Position** column of the lookup table **tblTigWelding**).



Assembly position affects travel speed, which affects TIG Welding Operation Weld Time, if the Linear Rate Weld Cycle Time Method is enabled.

Travel Speed

If the Linear Rate Weld Cycle Time Method is used, weld time is based, in part, on travel speed. By default, travel speed is derived from Weld Throat, Assembly Position, and Assembly Material Type—see TIG Welding Operation Weld Time. Users can override the default on a part-by-part basis with this setup option.

Number of Welding Passes

If the linear rate Weld Cycle Time Method is used, weld time is based, in part, on the number of welding passes used for weld (that is, the number of times the weld head traverses the length of the weld). By default, the number of passes is derived from Weld Throat—see TIG Welding Operation Weld Time. Users can override the default on a part-by-part basis with this setup option.

Gas Type used for Welding

By default, the type of gas used for welding is specified by the cost model variable `defaultTigWeldingGasType` (Argon in starting point VPEs). Users can override the default with this setup option. Gas type affects gas cost—see Additional Direct Costs for TIG Welding.

Enable Anti-Spatter Spray

By default in starting point VPEs, costs for antispatter spray are included in expendable tooling costs—see TIG Welding Expendable Tooling Calculation. Administrators can customize the default, and specify *no cost* for antispatter spray, by setting the cost model variable `weldAntiSpatterSprayEnabled` to `false`. Users can override the default on a per weld basis with this setup option.

Robotic Spot Welding Options

Robotic Spot Welding provides the following process-level option:

- **Number of operators tending to this machine:** By default this is the value of the machine property Number of Operators (1 in aPriori starting point VPEs). You

can override the default and specify a different number of operators, including a fractional number of operators.

Note that, unlike most processes in this process group, Robotic Spot Welding labor time is proportional to the number of operators, and cycle time is independent of the number of operators.

Select one of the following options

- **Default number of operators:** specified by the machine property **Number of Operators**.
- **User override value for this part:** enter a value greater than or equal to 0.

Electron Beam Welding Options

The Electron Beam Welding process provides the following options:

- Is the EB Welding Machine a Load Lock Machine
- Number of Parts in the Machine per Cycle
- Number of Operators
- Time to Load the Assembly
- Time to Unload the Assembly

The Electron Beam Welding operation provides the following option:

- Weld Speed

Is the EB Welding Machine a Load Lock Machine

By default, machine selection considers only standard and cycle machines. It does not include load lock machines for consideration, due to their higher purchase price and overhead. You can override the default, and direct machine selection to consider *only* load lock machines, by setting this setup option to **true**.

See [Process Time](#) for information about standard, cycle, and load lock machines. See also [Machine Selection](#).

Number of Parts in the Machine per Cycle

By default, the cost model assumes that each welding cycle handles one part. With this setup option, you can override the default. Choose one of the following:

- **Optimize Number of Parts for the selected machine:** this calculates the number of parts that can fit in the machine chamber (see [Machine Selection](#)).
- **User Override:** enter a number of parts.

Number of Operators

By default, this is the value of the machine property **Number of Operators** (1 in starting point VPEs). With this setup option, you can override the default, and specify a different number of operators.

Time to Load the Assembly

This is the time to load the machine for one welding cycle. By default, this is the product of per-part load time and [Number of Parts in the Machine per Cycle](#). Per-part load time is looked up by part weight in the lookup table **componentLoadTime**. See also [Process Time](#).

You can override the default with this setup option.

Time to Unload the Assembly

This is the time to unload the machine for one welding cycle. By default, this is the product of per-part unload time and [Number of Parts in the Machine per Cycle](#). Per-part unload time is looked up by part weight in the lookup table **componentLoadTime**. See also [Process Time](#).

You can override the default with this setup option.

Weld Speed

By default, this is calculated based on machine power and weld depth, and bounded above by the machine's maximum weld speed (see [Process Time](#)). You can override the default with this setup option.

Laser Welding Options

The Laser Welding process provides the following options:

- [Number of Parts in the Machine per Cycle](#)
- [Number of Operators](#)
- [Time to Load the Assembly](#)
- [Time to Unload the Assembly](#)

The Laser Welding operation provides the following option:

- [Weld Speed](#)

Number of Parts in the Machine per Cycle

By default, the cost model assumes that each welding cycle handles one part. With this setup option, you can override the default. Choose one of the following:

- **Optimize Number of Parts for the selected machine:** this calculates the number of parts that can fit in the machine chamber (see [Machine Selection](#)).
- **User Override:** enter a number of parts.

Number of Operators

By default, this is the value of the machine property **Number of Operators** (1 in starting point VPEs). With this setup option, you can override the default, and specify a different number of operators.

Time to Load the Assembly

This is the time to load the machine for one welding cycle. By default, this is the product of per-part load time and [Number of Parts in the Machine per Cycle](#). Per-part load time is looked up by part weight in the lookup table `componentLoadTime`. See also [Laser Welding Formulas](#).

You can override the default with this setup option.

Time to Unload the Assembly

This is the time to unload the machine for one welding cycle. By default, this is the product of per-part unload time and [Number of Parts in the Machine per Cycle](#). Per-part unload time is looked up by part weight in the lookup table `componentLoadTime`. See also [Laser Welding Formulas](#).

You can override the default with this setup option.

Weld Speed

By default, this is calculated based on machine power and weld depth, and bounded above by the machine's maximum weld speed (see [Laser Welding Formulas](#)). You can override the default with this setup option.

Mechanical Assembly Options

Each Mechanical Assembly operation provides options that allow you to specify the standard operation time as well as additional time for subcomponents with obstructed access or obstructed line of sight. You specify these values per subcomponent.

Nut Insert

Nut Insert provides the following option:

- **Nut Insert Obstructed Or Vision:** specifies whether there is an obstruction or vision problem that adds to the time required to perform the operation. By default this is **No obstructed access or vision problem**. You can override the default and specify one of the following:
 - Obstructed access OR vision problems (adds 2.5 seconds in aPriori starting point VPEs)
 - Obstructed access AND vision problems (adds 4 seconds in aPriori starting point VPEs)

The time added is looked up by the current process, operation, and PSO setting in the lookup table `tblMechanicalOperationTimes`. See [Nut Insert Operation Cycle Time](#).

Press Fit

Press Fit provides the following option:

- **Press Fit Obstructed Or Vision:** specifies whether there is an obstruction or vision problem that adds to the time required to perform the operation. By default this is

No obstructed access or vision problem. You can override the default and specify one of the following:

- Obstructed access OR vision problems (adds 2.5 seconds in aPriori starting point VPEs)
- Obstructed access AND vision problems (adds 4 seconds in aPriori starting point VPEs)

The time added is looked up by the current process, operation, and PSO setting in the lookup table **tblMechanicalOperationTimes**. See [Press Fit Operation Cycle Time](#).

Rivet

Rivet provides the following option:

- **Rivet Obstructed Or Vision:** specifies whether there is an obstruction or vision problem that adds to the time required to perform the operation. By default this is **No obstructed access or vision problem**. You can override the default and specify one of the following:
 - Obstructed access OR vision problems (adds 2.5 seconds in aPriori starting point VPEs)
 - Obstructed access AND vision problems (adds 4 seconds in aPriori starting point VPEs)

The time added is looked up by the current process, operation, and PSO setting in the lookup table **tblMechanicalOperationTimes**. See [Rivet Operation Cycle Time](#).

Screw Tighten - Manual

Screw Tighten – Manual provides the following option:

- **Screw Tighten Manual Obstructed Or Vision:** specifies whether there is an obstruction or vision problem that adds to the time required to perform the operation. By default this is **No obstructed access or vision problem**. You can override the default and specify one of the following:
 - Obstructed access OR vision problems (adds 5 seconds in aPriori starting point VPEs)
 - Obstructed access AND vision problems (adds 8 seconds in aPriori starting point VPEs)

The time added is looked up by the current process, operation, and PSO setting in the lookup table **tblMechanicalOperationTimes**. See [Screw Tighten - Manual Operation Cycle Time](#)

Screw Tighten - Power

Screw Tighten – Power provides the following option:

- **Screw Tighten Power Obstructed Or Vision:** specifies whether there is an obstruction or vision problem that adds to the time required to perform the operation. By default this is **No obstructed access or vision problem**. You can override the default and specify one of the following:

- Obstructed access OR vision problems (adds 2.5 seconds in aPriori starting point VPEs)
- Obstructed access AND vision problems (adds 4 seconds in aPriori starting point VPEs)

The time added is looked up by the current process, operation, and PSO setting in the lookup table **tblMechanicalOperationTimes**. See [Screw Tighten - Power Operation Cycle Time](#).

Snap Fit

Snap Fit provides the following option:

- **Snap Fit Obstructed Or Vision:** specifies whether there is an obstruction or vision problem that adds to the time required to perform the operation. By default this is **No obstructed access or vision problem**. You can override the default and specify one of the following:
 - Obstructed access OR vision problems (adds 2.5 seconds in aPriori starting point VPEs)
 - Obstructed access AND vision problems (adds 4 seconds in aPriori starting point VPEs)

The time added is looked up by the current process, operation, and PSO setting in the lookup table **tblMechanicalOperationTimes**. See [Snap Fit Operation Cycle Time](#).

Tab Bend

Tab Bend provides the following options:

- **Tab Bend Obstructed Or Vision:** specifies whether there is an obstruction or vision problem that adds to the time required to perform the operation. By default this is **No obstructed access or vision problem**. You can override the default and specify one of the following:
 - Obstructed access OR vision problems (adds 2.5 seconds in aPriori starting point VPEs)
 - Obstructed access AND vision problems (adds 4 seconds in aPriori starting point VPEs)

The time added is looked up by the current process, operation, and PSO setting in the lookup table **tblMechanicalOperationTimes**. See [Tab Bend Operation Cycle Time](#).

Process Defaults and Thresholds

This section lists some of the important cost model variables.

cycleTimeAdjustmentFactor	See process cycle time formulas, for example, Manual MIG Welding Process Cycle Time.
handlingMultiplier	See Pick and Place Options.
insertionMultiplier	See Pick and Place Options.
manualScrewTighteningObstructedAndVision	See Mechanical Assembly Options.
manualScrewTighteningObstructedOrVision	See Mechanical Assembly Options.
manualScrewTighteningTime	See Screw Tighten - Manual Operation Cycle Time.
nutInsertTime	See Nut Insert Operation Cycle Time.
nutInsertTimeObstructedAndVision	See Mechanical Assembly Options.
nutInsertTimeObstructedOrVision	See Mechanical Assembly Options.
powerScrewTighteningObstructedAndVision	See Mechanical Assembly Options.
powerScrewTighteningObstructedOrVision	See Mechanical Assembly Options.
powerScrewTighteningTime	See Screw Tighten - Power Operation Cycle Time.
pressFitTime	See Press Fit Operation Cycle Time.
pressFitTimeObstructedAndVision	See Mechanical Assembly Options.
pressFitTimeObstructedOrVision	See Mechanical Assembly Options.
reorientTime	See Reorient Operation Cycle Time Calculation.
rivetTime	See Rivet Operation Cycle Time.
rivetTimeObstructedAndVision	See Mechanical Assembly Options.
rivetTimeObstructedOrVision	See Mechanical Assembly Options.
snapFitTime	See Snap Fit Operation Cycle Time.
snapFitTimeObstructedAndVision	See Mechanical Assembly Options.
snapFitTimeObstructedOrVision	See Mechanical Assembly Options.
tabBendTime	See Tab Bend Operation Cycle Time.
tabBendTimeObstructedAndVision	See Mechanical Assembly Options.
tabBendTimeObstructedOrVision	See Mechanical Assembly Options.

Assembly Welds

To cost assembly welding, aPriori requires that each weld be defined in one of two ways:

- Pro Welds: defined in the Pro/Engineer CAD model.
- Virtual Welds: defined in aPriori.

For more information, see the *Weld GCDs* section of the aPriori *User Guide*.

This section has the following subsections:

- Pro Welds
- Virtual Welds

Pro Welds

You can edit a virtual or Pro weld by right-clicking the Weld GCD (in the Manufacturing Process or Geometric Cost Drivers pane) and selecting **Edit Operation**. The Welding dialog is displayed in the lower right-hand pane of the Operation Sequence dialog. For more information, see the *Weld GCDs* section of the aPriori *User Guide*.

In starting point VPEs, if aPriori is unable to obtain the width of a Pro weld from the values specified in the CAD model, it attempts to estimate the width in one of the following ways:

- Estimate the width from the actual as-modeled surface weld geometry (for "surface-type" welds). Administrators can disable this behavior by setting the site variable `deriveProWeldWidthFromGeometry` to **false**.
- Estimates the width based on the weld depth. Administrators can disable this behavior by setting the site variable `deriveProWeldWidthFromDepth` to **false**.

If aPriori is unable to obtain the width of a Pro weld from the values specified in the CAD model, and it uses neither of the above estimation methods, the width is set to 0.

aPriori sets to 0 width and depth values that it is unable to obtain or estimate. Welds with 0-valued width or depth have 0 volume and 0 cross-sectional area. In starting point VPEs, such welds fail to cost. To address missing dimension values, users can either update the Creo model parameters in Creo, or override the weld properties in aPriori.

Administrators can direct aPriori to cost 0-cross-sectional-area welds instead of failing them, by setting the cost model variable `failWeldsWithZeroCrossSectionArea` to **false**. Note that in this case, many components of cycle time are 0, but overall cycle time is not 0, since it includes components that are independent of weld dimensions.

Virtual Welds

To cost welds that have not been defined in the CAD model, aPriori allows users to create virtual welds. Once created, these virtual welds can be copied into other assemblies with substantially similar geometry (such as an assembly that has been

created due to a modification or part number change. When defining a weld as a virtual weld:

- A weld created in aPriori is associated with a reference or set of references (edges or datum curves) in the CAD model. By default, the total length of the weld is determined from the reference length. In this case, the total length is dynamic; if the CAD model reference length changes, so will the total length of the weld. You can also override the total length of the weld and specify a different value. In this case, the total length is not dynamic.
- You can specify the type of weld (for example, fillet or square groove) and the production mechanism (that is, manual or robotic).
- In most cases (except for spot welds), you can specify the weld width and depth.
- You can also specify whether the weld is intermittent or continuous. If the weld is intermittent, you can specify the segment length and the pitch. The number of segments is computed based on the total length, pitch, and segment length.

You work with virtual welds through the Component Viewer. For more information about how to create, copy, edit, and delete virtual welds, see *Using the Component Viewer tools and commands* in the User Guide chapter *Using aPriori Desktop*.

Assembly Views

When you open an assembly in aPriori, you have the ability to navigate the complete structure of the assembly in the Assembly Details Tab (the default view), or to see a summary of assembly costs via the Assembly Tracker tab.

The Assembly Details Tab

The Assembly Details tab supports two main layouts -- Tree (indented BOM structure) and List (component list view). You can toggle these views through the Options menu.

- Indented Structured Bill of Materials (BOM) View

The assembly is presented in a tree structure identical to the assembly structure as it is represented in the CAD application. You can expand and collapse the tree to any level.

The **Tree** view is not sortable because it is structured.

Each assembly and sub-assembly also includes an assembly processes line where you can expand to see the processes (i.e., welding, mechanical assembly, machining or surface treatment) that have been applied at the assembly level.

Always visible at the bottom of the table are the total costs of all components (Component Subtotal), the total costs of all assembly processes (Assembly Processes Subtotal) and the Grand Total for the entire assembly.

Uninitialized assemblies and parts will show dashes for costs.

Each sub-assembly will provide a subtotal of its components

You can apply a functional group template to an assembly. See the *Using functional groups* section of the aPriori User Guide for more information.

- Component List View

The component list view flattens the assembly structure and provides a complete grouped listing of parts, sub-assemblies and assembly processes within the top level assembly. For example, if a part occurs 10 times at 4 different levels in the assembly, it will show up 4 times in the **Tree** view, but only once in the **List** view with a quantity of 10.

This view is sortable within each category by selecting any of the table columns

- Other Assembly View Features

You can toggle between displaying the **Full Cost** of all parts in the assembly, or individual **Per Part Costs** with a selection in the Options menu. Note that in the 'Per Part Cost' mode, the component costs will not add up to the assembly totals as they represent only a single part instead of all parts in the assembly.

You can toggle between displaying **Current Values** (costs reflect all inputs selected in current session), **Previous Values** (costs do not include your last change) and **Saved Values** (cost values saved in the data base) from the options menu.

The table can be copied and pasted into an Excel spreadsheet. Use the **Copy Table** command in the **Edit** menu. Only the columns and rows displayed will be copied.

Both in the viewer and the assembly table you can **Initialize** or **Open** components through the right click menu.

Assembly Details Context Menu

Right-clicking on a row in the Assembly Details tab provides access to the follow commands:

Menu Command	Description
Copy Cut Paste	Basic editing commands for selected components. For example, you could copy or cut a component from one assembly and paste it into another assembly.
Add	When an assembly row is selected, Add provides the ability to add an existing component through the Search utility (see "Using the Search Tool" in the "aPriori Desktop Basics" chapter of the aPriori <i>User Guide</i>), or to create and add a new virtual component (see "Creating new components without CAD" in the "Using aPriori Desktop" chapter of the aPriori <i>User Guide</i>).
Edit Quantity	Specify the number of instances of the selected component.
Remove	Remove the selected component from the assembly.

Menu Command	Description
Switch Scenario	If the currently selected component has more than one scenario, this command allows you to choose between them.
Show Formula Dependencies	See the "Show Formula Dependencies" section in the <i>aPriori User Guide</i>
Initialize	If the selected row has a grey (uncosted) icon, use this command to populate the Cost Object Info window and cost the component.
Open	Opens the selected component in its own tab.
Save	Commits to the aPriori database any changes to the selected component.
Lock Unlock	Allow or disallow changes to the currently selected part or assembly scenario.
Ignore Undo Ignore	If a component scenario is set to "ignore", the component scenario will not be costed even if it is a sub-component of a deep costing assembly. The component is removed from the display, and its row in Assembly details is greyed and crossed out. See the note following this table.
Hide Undo Hide	If a component scenario is set to "hide", the component is removed from the display and its row in Assembly Details is greyed. However, hide status does not affect costing. Hide is useful for simply turning off the display of a component in an assembly view to view what is behind it. See the note following this table.

A note about Ignore, Hide, and their effect on costing

When you **Hide** a component scenario, you simply remove its display from the component viewer. Hiding a component has no effect when costing. When you **Ignore** a component scenario, you not only remove its display from the component viewer, you also remove it from costing operations, even if the component is a member of a deep costing assembly. However, ignoring a part does not recompute any geometry and does not change the envelope dimensions of the parent assembly. Therefore, the cost of a component calculated on its own will not necessarily be the same (or even close to) the cost of its parent assembly with all other components ignored. For example, consider an assembly consisting of three parts: P1, P2, and P3. Costing P1 by itself might result in a labor time of 30 seconds. Costing the entire assembly might result in a total labor time of 120 seconds. If you ignore parts P2 and P3 and then cost the assembly, the labor time will probably not be the 30 seconds of the single remaining part (P1). It might be closer to the total assembly time, minus some amount for the ignored parts, since the envelope dimensions of the assembly have not been recalculated.

Configurable Views

The Assembly Details tab offers the following pre-configured views: All Data, Weight Analysis, Sourcing Summary ,Assembly Summary, Quota View, and Manufacturing Details. The Part Details tab offers the following pre-configured views, including: All Data, Cost Details, Part Summary, Quote View, Manufacturing Details, and Sourcing Summary.. Users can also make additional views containing just the information of interest, organized in a specific order. For more information, see the "Creating New Views" section of the aPriori *User Guide*..

The Assembly Tracker Tab

The Assembly Tracker Tab provides a visual display of an assembly's cost. The tab has eight charts: Summary of Assembly Costs, Summary of Component Costs, Status of Component Costs, Type of Costs, Manufacturing Locations (VPE), Comparison of Alternatives, Finish Mass Target Analysis and Cost Target Analysis. You can choose which graphs to display from the Assembly Tracker menu bar by selecting Select Charts and checking or unchecking the graph titles.

Assembly Machining

aPriori currently is limited in its ability to cost assembly machining, due to limitations in detecting geometry that is machined at the assembly level rather than the piece part level. In particular, aPriori currently is unable to detect assembly cuts, holes and other material removal features in CAD assemblies when working with all CAD systems other than ProE/Creo in Direct integration. To support assembly machining cost estimates when working with non-PTC CAD systems, aPriori provides a mechanism for you to manually indicate the presence of common assembly milling operations. (Note that support for manually-defined turning operations on assemblies is not yet provided.) See [Virtual Machining](#) for more information.

5 Assembly Molding

This chapter describes the costing details and inputs that are available for the Assembly Molding process group. With this group, aPiori estimates times and costs for assemblies consisting of plastic-molded parts together with non-molded inserts.

This chapter has the following sections:

- Cost Model Overview for Assembly Molding
 - Geometric Cost Drivers for Assembly Molding
 - Routing and Feasibility for Assembly Molding
 - Machine Selection for Assembly Molding
 - Formulas for Assembly Molding
 - User Inputs for Assembly Molding
-

Cost Model Overview for Assembly Molding

The Assembly Molding process group models the processes involved in both insert molding and overmolding.

With insert molding, a plastic part is molded around metal inserts such as pins or bushings, as well as around larger, more complex inserts. Common examples of insert molded parts include electrical connectors, screwdrivers and other tools with plastic-coated handles, and plastic components with embedded, threaded metal bushings for fastening purposes.

With overmolding the insert is made of a polymer material. The insert is injection molded separately, and then subsequently placed in a second mold base and machine so that another polymer can be molded around it. Common examples of overmolded parts include toothbrush handles and wheels for toys and vacuum cleaners.

The Assembly Molding process group provides a single routing, which can be used to estimate the costs for both these manufacturing processes.

The Assembly Molding process group is similar to the [Plastic Molding Process Group](#), and many of the calculations and setup options are the same in both groups. In addition, Assembly Molding is similar to the Assembly process group with regard to the type of CAD file it extracts information from. As with the Assembly process group, the Assembly Molding process group extracts geometric information from a CAD file for an *assembly* of component parts.

With Assembly Molding, each component of the assembly is either a molded portion of the overall Assembly Molding part, or is a non-molded insert, placed into the mold (with some portion protruding out of the mold) prior to injection of plastic. A non-molded subcomponent can be a previously-costed metal part, Plastic Molding part, or Assembly Molding part.

You should cost non-molded subcomponents separately, using the appropriate process group, so that their costs are rolled into the cost of the finished molded assembly.

Note: *Molded subcomponents do not appear in the Assembly Details pane.* The injection molding costs are accounted for as process costs at the assembly level rather than at the plastic component level. This prevents any standalone scenarios of those components from rolling up into the assembly, which would double-count costs for that component.

The rest of this overview covers the following topics:

- [Processes for Assembly Molding](#)
- [Part Geometry for Assembly Molding](#)
- [Materials for Assembly Molding](#)
- [Machines for Assembly Molding](#)
- [Tooling for Assembly Molding](#)

- [Assumptions and Limitations for Assembly Molding](#)

Processes for Assembly Molding

Assembly Molding uses two main processes:

- **Insert Pick and Place:** accounts for labor and overhead costs for picking each non-molded subcomponent (out of a bin, for example), and placing it into the mold or onto an action mechanism. By default, times are based on subcomponent weight and loading method (manual or robotic). Users can configure the cost calculations with the per-Subcomponent setup options [Base Load Time](#), [Load time multiplier for handling difficulties](#), and [Load time multiplier for insertion difficulties](#).
- **Insert Injection Molding:** models the molding process, including injection of the material, cooling, and ejection of the part, and accounts for labor, overhead, material, and hard tooling costs. Users can configure the cost calculations largely as they would for Injection Molding in the Plastic Molding process group (see [User Inputs for Plastic Molding](#)).

Optional secondary processes are supported as well.

Part Geometry for Assembly Molding

GCDs in the Assembly Molding process group include all GCDs in the Plastic Molding process group (see [GCD Extraction for Plastic Molding](#)). Assembly Molding also includes two important, additional GCD types:

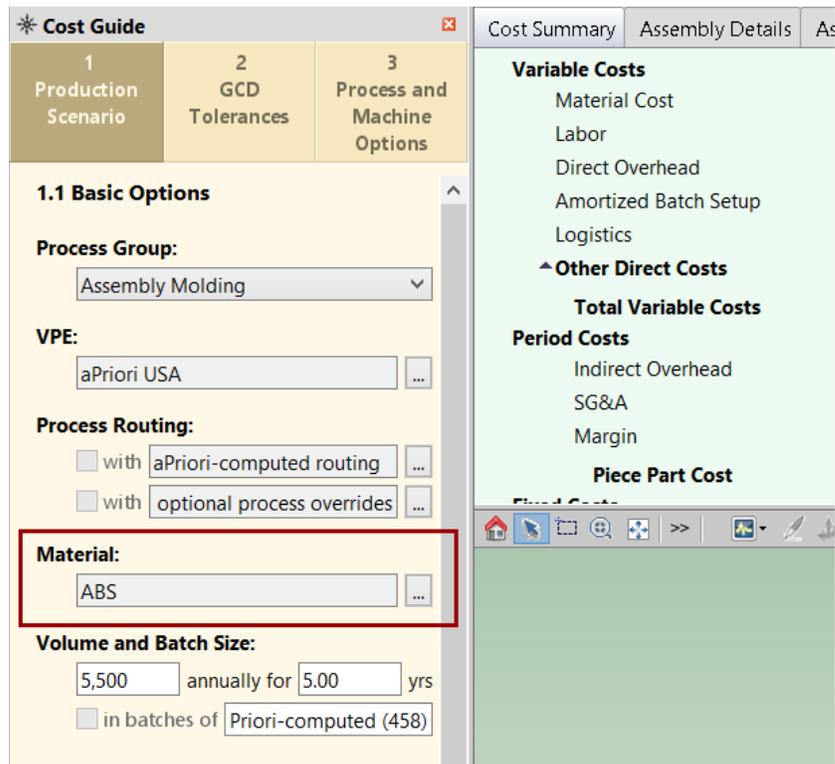
- **Subcomponent:** each Subcomponent GCD represents either a molded portion of the part or a non-molded insert. A Subcomponent's **Is Molded** property is **true** for molded components and **false** for inserts.
Note: If you want to override aPriori's classification of a Subcomponent, you can edit the value of **Is Molded** in the Geometric Cost Drivers pane.
- **Region:** a Region GCD represents a portion of an insert that is exposed to air (that is, not surrounded by molded plastic). Prior to injection, some inserts must be held in place in the mold by a retention tool. Region GCDs represent candidate regions of contact between tool and insert. Their accessibility relations help aPriori determine the tool's likely orientation, which aids in the calculation of tooling costs.

See [Geometric Cost Drivers for Assembly Molding](#) for more information.

Materials for Assembly Molding

The Assembly Molding cost model supports the molding of thermoplastic materials, and assumes that the material is delivered in pellet form. The model relies on the same material properties as the Plastic Molding process group--see [Materials for Plastic Molding](#).

With Assembly Molding, as with the Assembly process group, you *cannot* access the Material Selection dialog from the Manufacturing Process pane. Once GCDs have been extracted from the CAD model, you can access the Material Selection dialog from the Production Scenario tab of the Cost Guide (click ... in the **Material:** field):



The default material for Assembly Molding is ABS.

The material you select specifies the material for all the molded Subcomponents. For more information, see [Materials for Plastic Molding](#). See also Material Cost in [Insert Injection Molding Formulas](#).

Machines for Assembly Molding

In starting point VPEs, the Insert Pick and Place process selects one of three virtual machines, reflecting either manual or robotic pick and place:

- Manual: inserts are loaded into the mold manually.
- 3-axis: inserts are loaded into the mold with a 3-axis robot.
- 6-axis: inserts are loaded into the mold with a 6-axis robot.

Users can request a particular type of machine (manual, 3-axis, or 6-axis) with the setup option [Manual or Robotic Loading](#).

Insert Injection Molding machines are assumed to perform single-shot, single-material, single-color molding. The machines are typically vertical (with a vertical draw direction), but horizontal machines are included in starting point VPEs as well. Some vertical

machines have a shuttle or rotary table, which allows inserts to be loaded into one mold while injection molding is performed with another mold.

Users can request a particular machine orientation (vertical or horizontal) or a particular table orientation (no table, shuttle, or rotary) with the setup options [Insert Injection Molding Machine Orientation](#) and [Vertical Table Configuration](#).

Brand names of IM and SFM machines in the baseline VPE include the following:

- Arburg
- Engel
- Magna
- Milacron
- PRM

Starting point VPEs also include a number of virtual machines.

The characteristics of these machines fall into the following ranges:

Machine Characteristic	Low End	High End
Overhead Rate (USD/hr)	2.23	192.03
Dry Cycle Time (sec)	2	12.5
Injection Rate (mm ³ /sec)	26,000	3,710,000
Clamping Force (kN)	27.22	55,000
Shot Size (g)	9.5	72,000
Max Mold Height (mm)	175	2,500
Min Mold Height (mm)	100	1,500
Vertical and Horizontal Tie Bar Distance (mm)	300	2,500

See [Machine Selection for Assembly Molding](#) for more information.

Tooling for Assembly Molding

The hard tooling model for Assembly Molding is largely the same as the Plastic Molding tooling model (see [Tooling for Plastic Molding](#) and [Tooling Cost](#)). However, the Assembly Molding tooling calculations are affected by several factors not present in Plastic Molding:

- Assembly Molding parts may require inter-component runners, that is, runners between the molded Subcomponents of a part (if there are multiple molded Subcomponents). See [Runner Volume and Runner Area for Assembly Molding](#).
- Assembly Molding parts may require retention tools, which hold non-molded Subcomponents in place prior to injection. See [Insert Retention Cost](#).

- Assembly Molding parts may require slides or lifters that withdraw retention tools after cooling and prior to the opening of the mold. See [Geometric Cost Drivers for Assembly Molding](#).
- For machines with a shuttle or rotary table (see [Machines for Assembly Molding](#)), tooling is assumed to include two mold lower halves and one mold upper half, by default in starting point VPEs. This allows one lower half to be loaded while the other (together with the tool upper half) is injected (see [Formulas for Assembly Molding](#)). Administrators can customize the default number of lower tools with the cost model variable **defaultNumMoldToolsPerTable**. Users can override the default on a per-part basis with the setup option [Number of Mold Tools Per Table](#).

Note that, in the case of a part with multiple molded Subcomponents, the cost model uses the term 'cavity' to refer to the mold cavity for the entire molded portion of the Assembly Molding part, rather than to the cavity for a single molded Subcomponent. So, for example, 'Number of Mold Cavities' refers to the number of top-level Insert Molding parts that are handled by the mold.

Assumptions and Limitations for Assembly Molding

The Assembly Molding process group is subject to the following limitations:

- The molded plastic components of an Assembly Molding assembly do not appear in the Assembly Details pane. This is for two reasons:
 - The injection molding costs are accounted for as process costs at the assembly level rather than at the plastic component level.
 - Excluding the plastic components prevents any standalone scenarios of those components from rolling up into the assembly, effectively double-counting costs for that component. While users are advised not to cost these plastic components as standalone parts since they are in fact molded in the context of the assembly, there is no way to prevent this.
- aPriori requires that the hierarchy of the assembly CAD model correspond to the actual manufacturing order to accurately estimate the cost of an Assembly Molding assembly. In particular, aPriori interprets all the molded components that are at the same level of the assembly hierarchy as being molded simultaneously, in a single mold cavity with the same screw unit. If the CAD model hierarchy structure doesn't match the manufacturing order, various aspects of the aPriori analysis may be inaccurate including the number of distinct molding operations, the number and size of mold bases, the draw direction(s), parting lines, and number and types of side actions.

Geometric Cost Drivers for Assembly Molding

GCDs in the Assembly Molding process group include all GCDs in the Plastic Molding process group (see [GCD Extraction for Plastic Molding](#)). Assembly Molding also includes two important, additional GCD types:

- **Subcomponent:** each Subcomponent GCD represents either a molded portion of the part or a non-molded insert. Each part can have one or more molded Subcomponents and one or more inserts. A Subcomponent's **Is Molded** property is **true** for molded Subcomponents and **false** for inserts.

Note: If you want to override aPiori's classification of a Subcomponent, you can edit the value of **Is Molded** in the Geometric Cost Drivers pane.

Prior to injection, some non-molded Subcomponents must be held in place in the mold by a retention tool, that is, either an action (slide or lifter) or a fixed tool. A Subcomponent is bundled onto a SlideBundle or LifterBundle when the tool required to hold the Subcomponent in place prior to injection would prevent the mold from opening, were it not withdrawn by the motion of an action after cooling and prior to opening.

Each Subcomponent GCD appears in the Geometric Cost Drivers pane either under **Component** (if it is not bundled) or under a SlideBundle or LifterBundle GCD (if it is bundled).

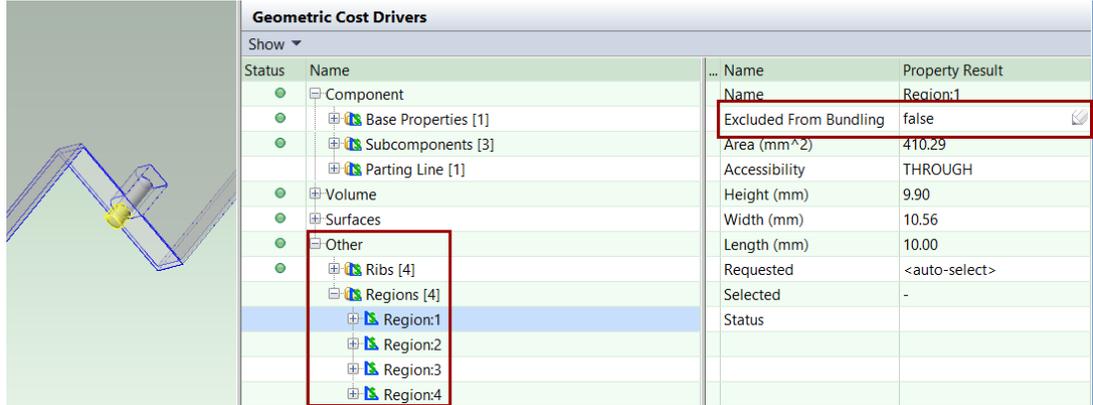
Geometric Cost Drivers		...	
Status	Name	Name	Property Result
●	Component	Part Number	insert_bush_inch
●	Base Properties [1]	Is Molded	false
●	Subcomponents [3]	Excluded From Bundling	false
●	PLASTIC2 (Subcomponent:1)	Mass (kg)	0.01
●	INSERT_PIN_INCH (Subcomponent:4)	Length (mm)	25.40
●	INSERT_PIN_MMB (Subcomponent:5)	Width (mm)	10.00
●	Parting Line [1]	Height (mm)	10.00
●	Volume	Surface Area (mm^2)	1,493.08
●	Slide Bundles [2]	Volume (mm^3)	717.03
●	SlideBundle:1	Time (s)	8
●	INSERT_BUSH_INCH (Subcomponent:2)	Status	●
●	GCD Relations		
●	SlideBundle:2		
●	INSERT_BUSH_MM (Subcomponent:3)		
●	SimpleHole:1		
●	GCD Relations		

Note: If you want to override aPiori's assignment of a given Subcomponent to a bundle, you can edit a Subcomponent's **Excluded From Bundling** property. If you set this property to **true**, the Subcomponent will not be assigned to a slide or lifter bundle.

- **Region:** a Region GCD represents a portion of a non-molded Subcomponent that is exposed to air (that is, not surrounded by molded plastic). If a Region GCD represents a portion of a given Subcomponent, it bears the **Lies On** relation to that Subcomponent.

Each Region has exactly one associated non-molded Subcomponent. Each non-molded Subcomponent has one or more associated Regions.

Regions appear under **Other** in the Geometric Cost Drivers pane.



The screenshot shows the 'Geometric Cost Drivers' window. On the left is a 3D model of a mechanical part. The main area is a tree view showing the hierarchy: Component, Base Properties [1], Subcomponents [3], Parting Line [1], Volume, Surfaces, Other, Ribs [4], and Regions [4]. Under 'Regions [4]', there are four entries: Region:1, Region:2, Region:3, and Region:4. A red box highlights the 'Regions [4]' folder and its sub-items. To the right is a table of properties for the selected 'Region:1'.

Name	Property Result
Excluded From Bundling	false
Area (mm^2)	410.29
Accessibility	THROUGH
Height (mm)	9.90
Width (mm)	10.56
Length (mm)	10.00
Requested	<auto-select>
Selected	-
Status	-

A Subcomponent's associated Region GCDs are used as candidates for the regions of the Subcomponent that are held by a retention tool. aPriori analyses the accessibility of these regions, in order to determine the tool's likely orientation. The tool's orientation helps determine whether the component requires bundling onto a slide or lifter, and which other Subcomponents it should be bundled with (see Subcomponent, above).

Note: if you want to exclude a given Region from consideration as the region of contact between a retention tool and an insert, you can edit the Region's **Excluded From Bundling** property. If you set this property to **true**, the Region will *not* be chosen as the region of contact for a retention tool; aPriori will determine the tool orientation based on the choice of a different Region that lies on the same Subcomponent.

Note: if you edit **Is Molded** or **Excluded From Bundling** properties, you must be CAD-connected; geometry re-extraction is required for GCD property edits to affect costing.

Routing and Feasibility for Assembly Molding

Process routing, process feasibility, and operation assignment for Assembly Molding are covered in the following sections:

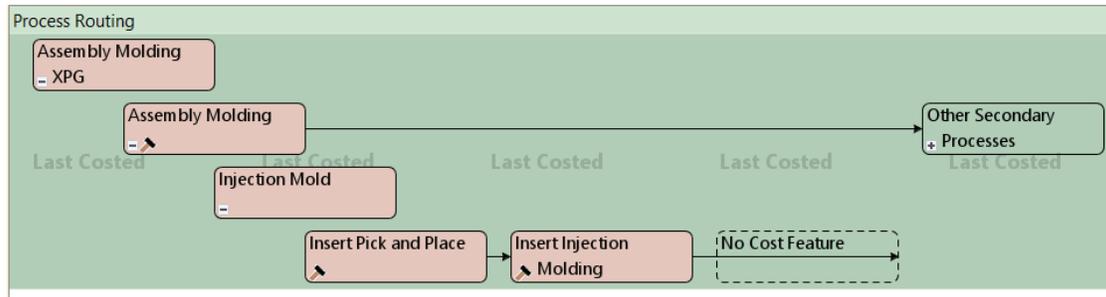
- Process Routing for Assembly Molding
- Process Feasibility for Insert Injection Molding
- Operation Assignment for Insert Pick and Place
- Operation Assignment for Insert Injection Molding

Process Routing for Assembly Molding

Assembly Molding parts are routed to the following two processes, optionally followed by secondary processes:

- Insert Pick and Place: models picking each non-molded subcomponent, and loading it into the mold.

- Insert Injection Molding: models the molding process, including injection of the material, cooling, and ejection of the part, and accounts for material costs and hard tooling costs.



Manufacturing Process	
Edit	View
Primary Process Group: Assembly Molding	
... Process Step	
[-]	ASSY_MM_INCH
[+]	Assembly Molding
[-]	Injection Mold
[+]	Insert Pick and Place
[+]	Insert Injection Molding

Note that No Cost Feature is never included in the Routing.

Process Feasibility for Insert Injection Molding

The Insert Injection Molding process is feasible only if both the following hold:

- Material: plastic material is compatible with injection molding, that is, the material property **Can IM_SFM** is set to **true**.
- Wall thickness: part wall thickness is in range, if **Minimum Wall Thickness Check** and/or **Maximum Wall Thickness Check** are enabled (they are disabled by default). The maximum and/or minimum allowable thicknesses are looked up by material type and process name in the lookup table **tblWallThickness**.

Material Type	Maximum Wall Thickness (mm)	Minimum Wall Thickness (mm)	Process Name
ABS	3.55600	1.14300	Insert Injection Molding
ABS	15.00000	2.03200	Insert Structural Foam Molding
Acetal	3.04800	0.76200	Insert Injection Molding
Acetal	15.00000	2.03200	Insert Structural Foam Molding
Nylon	2.92100	0.76200	Insert Injection Molding
Nylon	15.00000	2.03200	Insert Structural Foam Molding
Nylon	50.80000	1.52400	Insert Reaction Injection Molding
PET	5.08000	0.76200	Insert Injection Molding
PET	15.00000	2.03200	Insert Structural Foam Molding
Polycarbonate	3.81000	1.01600	Insert Injection Molding
Polycarbonate	15.00000	2.03200	Insert Structural Foam Molding
Polypropylene	3.81000	0.63500	Insert Injection Molding
Polypropylene	15.00000	2.03200	Insert Structural Foam Molding
Polystyrene	3.81000	0.88900	Insert Injection Molding
Polystyrene	15.00000	2.03200	Insert Structural Foam Molding
Polyurethane	50.80000	1.52400	Insert Reaction Injection Molding

Operation Assignment for Insert Pick and Place

Any Subcomponent that is not molded is assigned either the Manual Load or Robotic Load operation of the Insert Pick and Place process. Each of these operations accounts for the time to load a mold insert into the mold or onto a slide or lifter, performed either manually or robotically:

- Manual Load is assigned to a Subcomponent if both the following hold:
 - The Subcomponent is *not* a molded component; that is, the geometric property **Is Molded** is **false**.
 - The process-level setup option **Manual or Robotic Loading** is set to **Manual**, which is the default setting in starting point VPEs. Administrators can customize the default with the cost model variable **loadManualOrRobotic**.
- Robotic Load is assigned to a Subcomponent if both the following hold:
 - The Subcomponent is *not* a molded component; that is, the geometric property **Is Molded** is **false**.
 - The process-level setup option **Manual or Robotic Loading** is set to **3-axis or 6-axis**. The default setting in starting point VPEs is **Manual**. Administrators can customize the default with the cost model variable **loadManualOrRobotic**.

Molded subcomponents are assigned the no-cost operation As Molded.

Note that agreement with **Manual or Robotic Loading** is a feasibility requirement for these operations. *Do not* override feasibility checks and manually assign different loading operations to different subcomponents. The same loading operation must be assigned to all non-molded subcomponents, or operation results will be incorrect (cycle times will reflect the assigned operations, but labor times will reflect the setting of **Manual or Robotic Loading**).

Operation Assignment for Insert Injection Molding

Operation assignment fails for GCDs with insufficient draft or with edge radii that are too small, provided that you enable the relevant checks by setting one or both of the following top-level setup options:

- **Draft Angle Check:** the lookup table **tblDraftAngle** specifies the minimum recommended draft angle for each material and process (only Insert Injection Molding is currently supported).

Material Type	Min Draft Angle (deg)	Process Name
ABS	0.25	Insert Injection Molding
ABS	0.50	Insert Structural Foam Molding
Acetal	0.25	Insert Injection Molding
Acetal	0.50	Insert Structural Foam Molding
Nylon	0.25	Insert Injection Molding
Nylon	0.25	Insert Reaction Injection Molding
Nylon	0.25	Insert Structural Foam Molding
PET	0.25	Insert Injection Molding
PET	0.50	Insert Structural Foam Molding
Polycarbonate	0.25	Insert Injection Molding
Polycarbonate	0.50	Insert Structural Foam Molding
Polypropylene	0.25	Insert Injection Molding
Polypropylene	0.50	Insert Structural Foam Molding
Polystyrene	0.25	Insert Injection Molding
Polystyrene	0.50	Insert Structural Foam Molding
Polyurethane	0.25	Insert Reaction Injection Molding

If draft checking is enabled and the draft angle of a GCD is less than the relevant minimum, the GCD fails to cost.

- **Minimum Edge Radius Check:** the lookup table **tblMinEdgeRadius** specifies the minimum recommended edge radius for each material and process.

tblMinEdgeRadius			
Material Type	Min External Radii (mm)	Min Internal Radii (mm)	Process Name
ABS	0.38100	0.12700	Insert Injection Molding
ABS	1.52400	1.52400	Insert Structural Foam Molding
Acetal	0.38100	0.12700	Insert Injection Molding
Acetal	1.52400	1.52400	Insert Structural Foam Molding
Nylon	0.38100	0.12700	Insert Injection Molding
Nylon	0.76200	1.58750	Insert Reaction Injection Molding
Nylon	1.52400	1.52400	Insert Structural Foam Molding
PET	0.38100	0.12700	Insert Injection Molding
PET	1.52400	1.52400	Insert Structural Foam Molding
Polycarbonate	0.38100	0.12700	Insert Injection Molding
Polycarbonate	1.52400	1.52400	Insert Structural Foam Molding
Polypropylene	0.38100	0.12700	Insert Injection Molding
Polypropylene	1.52400	1.52400	Insert Structural Foam Molding
Polystyrene	0.38100	0.12700	Insert Injection Molding
Polystyrene	1.52400	1.52400	Insert Structural Foam Molding
Polyurethane	0.76200	1.58750	Insert Reaction Injection Molding

If edge radius checking is enabled, and the radius of a GCD is less than the relevant minimum, the GCD fails to cost.

Machine Selection for Assembly Molding

Machine selection for Assembly Molding is covered in the following sections:

- Machine Selection for Insert Pick and Place
- Machine Selection for Insert Injection Molding

Machine Selection for Insert Pick and Place

In starting point VPEs, the Insert Pick and Place process selects one of three virtual machines, reflecting either manual or robotic pick and place:

- Manual
- 3-axis
- 6-axis

By default in starting point VPEs, the cost model selects the machine whose value for the **Name** property is **Manual**. Administrators can customize the default with the cost model variable **loadManualOrRobotic**. Users can override the default with the setup option **Manual or Robotic Loading**.

Machine Selection for Insert Injection Molding

If aPiori is configured to automatically select a machine, it selects the machine with the lowest clamp force that satisfies all the feasibility rules.

The feasibility rules require all the following:

- The mold required for the part can fit on the machine.
- The clamp force required for the part can be achieved by the machine.
- The shot size required for the part can be provided by the machine.
- The machine can open wide enough for the part to be removed.
- The machine's orientation (vertical or horizontal) is compatible with the Machine Orientation setup option (which is set to Vertical, by default).
- The machine's orientation is horizontal if the Eject Method setup option is set to Gravity.
- The machine's table type (rotary, shuttle, or no table) matches the Table Configuration setup option (which is set to No table, by default).

More specifically, a machine is feasible only if all the following are true:

- Machine clamp force is greater than or equal to the required force (see [Required Clamp Force](#) in the Plastic Molding chapter).
- Required shot size (see [Required Shot Size](#) in the Plastic Molding chapter) is a sufficiently small fraction (0.75 in starting point VPEs) of the machine property **Shot Size**. VPE administrators can customize the fraction with the cost model variable **recommendedShotSizeLimitUpper**.
- Required shot size (see [Required Shot Size](#) in the Plastic Molding chapter) is a sufficiently *large* fraction of the machine property **Shot Size**. VPE administrators

can customize the fraction with the cost model variable **recommendedShotSizeLimitLower** (0 in starting point VPEs).

- Machine property **Platen Width** is greater than or equal the mold base width. For horizontal machines, if the machine property **Platen Width** is not populated with a value, the machine property **Tie Bar Distance , Vert** is used.
- Machine property **Platen Length** is greater than or equal the mold base length. For horizontal machines, if the machine property **Platen Length** is not populated with a value, the machine property **Tie Bar Distance , Hor** is used.
- Machine property **Max Mold Height** is greater than or equal to the mold base height.
- Travel distance for mold open or close (see **Travel Distance** in [Insert Injection Molding Formulas](#)) does not exceed the machine's **Opening Stroke**.
- The setup option [Insert Injection Molding Machine Orientation](#) either is **No Preference** or matches the machine property **Orientation**. The setup option is set to **Vertical** by default in starting point VPEs.
- The machine property **Orientation** is **Horizontal** if the setup option [Part Eject Method](#) is set to **Gravity**. The setup option is set to **Manual** by default.
- The machine property **Table Configuration** matches the setup option [Vertical Table Configuration](#). The setup option is set to **No Table** by default in starting point VPEs.

Note: since no horizontal machine has a rotary or shuttle table, the setup option [Vertical Table Configuration](#) must be set to **No Table**, if the setup option [Insert Injection Molding Machine Orientation](#) is set to **Horizontal**; otherwise, no machine will be considered feasible.

Note: since no vertical machine can support part removal by gravity drop, the setup option [Part Eject Method](#) must be set to **Manual** (the default in starting point VPEs) or **Robotic**, if the setup option [Insert Injection Molding Machine Orientation](#) is set to **Vertical**; otherwise, no machine will be considered feasible.

aPriori calculates the mold dimensions, clamp force, and shot size required for a given part based on a number of factors, including the number of cavities in the mold. The number of cavities defaults to one, but can be specified in **Process Setup Options** or calculated by aPriori. Calculation of required shot size, required clamp force, and number of cavities is described in more detail in the Plastic Molding chapter: [Required Shot Size](#), [Required Clamp Force](#), and [Number and Layout of Mold Cavities](#).

aPriori selects only from preferred machines, if there is a feasible preferred machine and the cost model variable **usePreferredMachines** is set to **true** (the default in starting point VPEs). If there is no feasible preferred machine, or if the cost model variable **usePreferredMachines** is set to **false**, aPriori selects from all machines. A machine is preferred if the machine property **isPreferred** (typically displayed as **Is Preferred**) is **true**.

To manually select a machine for a given process, select **Edit > Routing Selection** in the Manufacturing Process pane, right-click on the process in the Routing Selection window, and select **Machine Selection** from the context menu (see also [Selecting a machine for an operation in Manufacturing Process Information](#)).

Formulas for Assembly Molding

Formulas for Assembly Molding are covered in the following sections:

- Insert Pick and Place Process Formulas
- Insert Pick and Place Operation Formulas
- Insert Injection Molding Formulas
- Runner Volume and Runner Area for Assembly Molding
- Yields for Assembly Molding

Insert Pick and Place Process Formulas

Labor Cost = Labor Time * Labor Rate / Final Yield

Labor cost depends on the following:

- Labor time (see formula)
- Labor rate (specified by the machine property **Labor Rate**)
- Final yield (see [Yields for Assembly Molding](#))

Labor Time = Cycle Time * Number of Operators * Labor Time Standard

Labor time is the product of the following:

- Cycle time: see formula.
- Number of operators: by default, this is specified by the machine property **Number of Operators**. Users can override the default with the setup option [Number of Operators](#).
- Labor time standard: specified as the machine property **Labor Time Standard**. This multiplier is used to account for otherwise unaccounted for factors that affect labor time, such as operator fatigue or time spent by the operator for cleaning or maintenance.

Cycle Time = Process Time * Cycle Time Adjustment Factor

Cycle time is the product of the following:

- Process time: see **Process Time**, below.
- Cycle time adjustment factor: specified by the cost model variable **cycleTimeAdjustmentFactor** (1 in starting point VPEs). Administrators can customize this value in order to globally adjust cycle times for Assembly Molding.

Process Time

The method of process-time calculation depends in the **Table Configuration** of the current Insert Injection Molding machine.

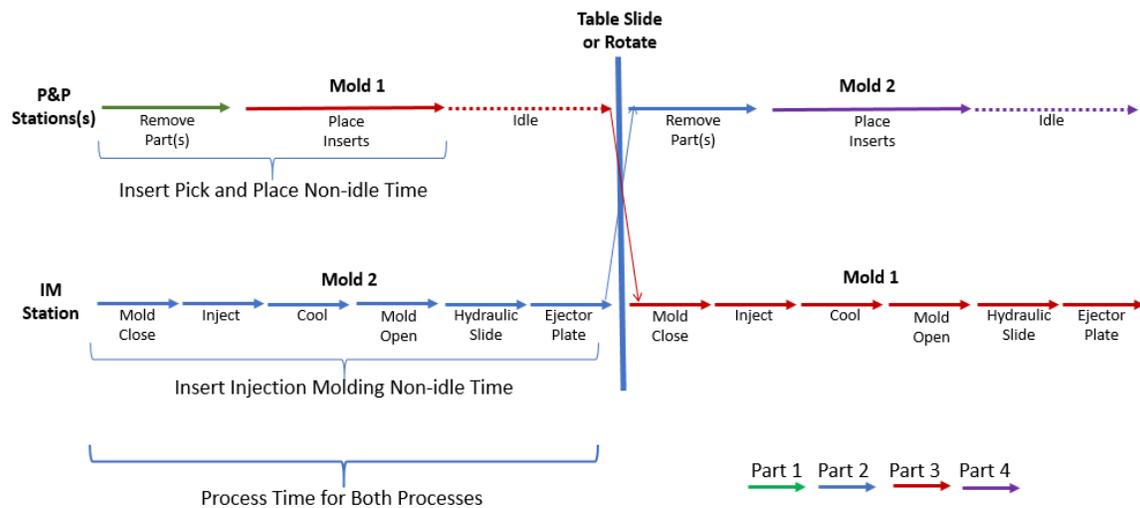
Process Time No Table =
(Pick and Place Non-idle Time + Insert Injection Molding Non-idle Time) /
Number of Cavities

If the machine selected for Insert Injection Molding has no table (as specified by the machine property **Table Configuration**), Insert Pick and Place operators are idle during Insert Injection Molding tasks. In this case, Insert Pick and Place process time depends on the following:

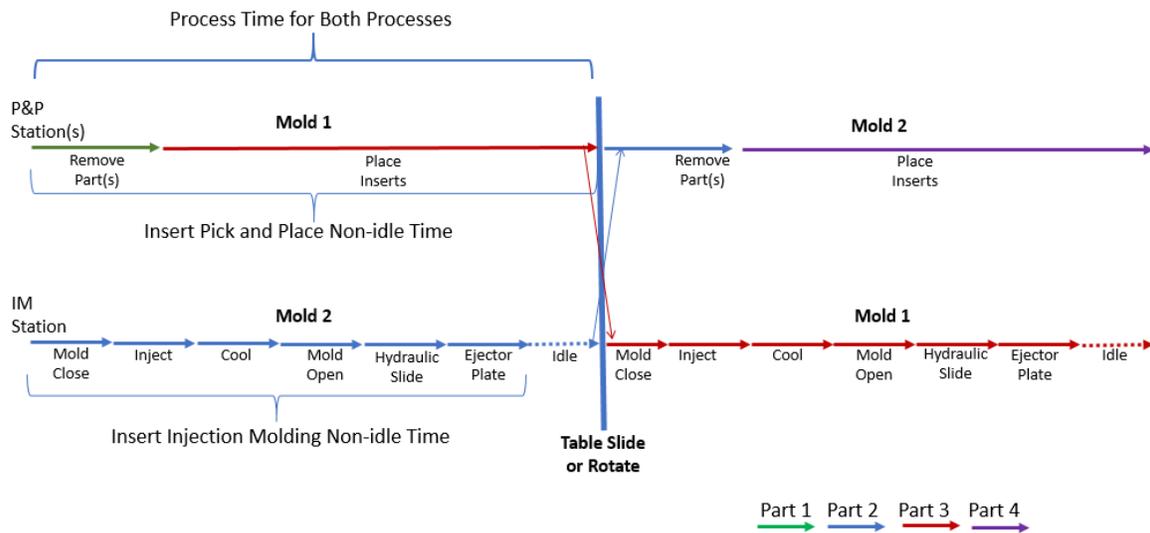
- Pick and Place non-idle time (see formula)
- Insert Injection Molding non-idle time (see formula)
- Number of mold cavities (see [Number and Layout of Mold Cavities](#) in the Plastic Molding chapter)

Process Time Shuttle or Rotary =
max (Pick and Place Non-idle Time, Insert Injection Molding Non-idle Time) /
Number of Cavities

If the machine selected for Insert Injection Molding has a rotary or shuttle table (as specified by the machine property **Table Configuration**), Insert Pick and Place operators can work with one or more lower tools (removing parts and then placing inserts) while Insert Injection Molding operators use another lower tool together with the upper tool (for injection and cooling). Pick and Place Operators are idle during a cycle only if injection and cooling takes longer than removing parts and placing inserts. In this case, the two parallel streams of activity might be represented as follows:



On the other hand, if removing parts and placing inserts takes longer than injection and cooling, Insert Injection Molding operators are idle during each cycle. In this case, the two parallel streams of activity might be represented as follows:



For manual loading (see [Manual or Robotic Loading](#)), increasing the number of Insert Pick and Place operators is assumed to decrease the total time required to place inserts.

Insert Pick and Place process time depends on the following:

- Pick and Place non-idle time (see formula)
- Insert Injection Molding non-idle time (see formula)
- Number of mold cavities (see [Number and Layout of Mold Cavities in the Plastic Molding](#) chapter)

**Pick and Place Non-idle Time =
Part Removal Time +
((Child Operation Times * Number of Cavities) / Number of Operators)**

Pick and Place non-idle time is the time required to remove parts from one mold and then place all inserts into it. It depends on the following:

- Part removal time: depends on how the setup option [Part Eject Method](#) is set:
 - **Robotic:** part removal time is the value of the cost model variable **robotGrabTime** (6 seconds in starting point VPEs).
 - **Manual:** part removal time is the value of the cost model variable **manualGrabTime** (8 seconds in starting point VPEs).
 - **Gravity:** part removal time is the value of the cost model variable **gravityDropTime** (1.25 seconds in starting point VPEs).

The default in starting point VPEs is **Manual**. Administrators can customize the default with the cost model variable **ejectMethod**.

Note that, with multiple cavities, it is assumed that all parts are removed at once, regardless of eject method.

- Child operation cycle times for Insert Pick and Place (see [Insert Pick and Place Operation Formulas](#))

- Number of Mold Cavities (see [Number and Layout of Mold Cavities](#) in the Plastic Molding chapter)
- Number of operators for Pick and Place: For manual loading (when [Manual or Robotic Loading](#) is set to **Manual**), this is specified by the machine property **Number of Operators**, by default. Users can override the default with the setup option [Number of Operators](#). For robotic loading (when [Manual or Robotic Loading](#) is set to **3-axis** or **6-axis**.), this is assumed to be 1, regardless of how [Number of Operators](#) is set.

Insert Injection Molding Non-idle Time =
Mold Close Time +
Injection Time +
Cool Time +
Hydraulic Slide Time +
Mold Open Time +
Ejector Plate Time

Insert Injection Molding non-idle time is the sum of the following:

- Mold close time (see [Insert Injection Molding Formulas](#))
- Injection time (see [Insert Injection Molding Formulas](#))
- Cool time (see [Insert Injection Molding Formulas](#))
- Hydraulic slide time (see [Insert Injection Molding Formulas](#))
- Mold open time (see [Insert Injection Molding Formulas](#))
- Ejector plate time (see [Insert Injection Molding Formulas](#))

Amortized Batch Setup =
(Setup Time * (Labor Rate + Direct Overhead Rate)) / Batch Size

Amortized batch setup is the cost per part for setting up one production batch for the current process. Starting point VPEs assume that there is *no* batch setup associated with the Pick and Place process, but VPE administrators can configure the cost model to include setup cost (by setting the machine property **Setup Time** to a nonzero value).

Setup cost depends on the following:

- Setup time (specified as the machine property **Setup Time**)
- Labor rate (specified by the machine property **Labor Rate**)
- Direct overhead rate (see [Direct and Indirect Overhead](#))
- Batch size (specified in the **Production Scenario** screen of the Cost Guide)

Note that indirect overhead depends on cycle time, while direct overhead depends on labor time.

Insert Pick and Place Operation Formulas

Cycle Time

Cycle time is load time (see formulas below).

Load Time for Manual Load = Weight Based Time * Handling Difficulty Factor * Insertion Difficulty Factor

Load Time for Robotic Load = Weight Based Time

Load time is the time it takes to pick one non-molded subcomponent of a part and place it into the mold or onto an action mechanism. Load time is looked up by part weight in the lookup table `tblComponentLoadTime`, or specified by the user with the setup option `Base Load Time`. For Manual Load (see [Manual or Robotic Loading](#)), this value is adjusted based on any special handling and/or insertion difficulties. Load time depends on the following:

- Weight based time: by default, this is looked up by part weight and load method (Manual or Robotic) in the lookup table `tblComponentLoadTime`.

Load Time (s)	Weight (kg)	Load Method
0.00	0.00	Manual
0.00	0.00	Robotic
6.00	0.50	Robotic
8.00	0.20	Manual
13.00	1.00	Robotic
15.00	1.00	Manual
16.00	5.00	Robotic
18.00	5.00	Manual
22.00	20.00	Robotic
24.00	20.00	Manual
30.00	27.00	Robotic
32.00	27.00	Manual
85.00	999,999,999.00	Robotic
87.00	999,999,999.00	Manual

If the lookup table lacks the required data, load time is specified by the cost model variable `defaultManualLoadTime` (8 seconds in starting point VPEs). Users can override the default, and specify the base load time with the setup option `Base Load Time`.

- Handling difficulty factor (Manual Load only): this is a factor that accounts for any special handling difficulties, such as those caused by component nesting, stickiness, or fragility.

By default this is 1 (that is, no special handling difficulties are assumed, by default). Users can use the setup option `Load time multiplier for handling difficulties` to set the factor to a standard value (specified by the cost model variable `handlingMultiplier--1.15` in starting point VPEs) or to specify the factor explicitly.

- Insertion difficulty factor (Manual Load only): this is a factor that accounts for any special insertion difficulties, for example, difficulties with alignment and positioning due to obstructed access, obstructed vision, or lack-of-alignment features such as chamfers and lead-ins.

By default this is 1 (that is, no special handling difficulties are assumed, by default). Users can use the setup option [Load time multiplier for insertion difficulties](#) to set the factor to a standard value (specified by the cost model variable `insertionMultiplier`--1.2 in starting point VPEs) or to specify the factor explicitly.

Insert Injection Molding Formulas

Material Cost =

$$\text{Material Cost} = \frac{\text{Molded Subcomponent Volume} * \text{Cost per Volume}}{\text{Utilization} * \text{Final Yield}}$$

Material cost is calculated as for Injection Molding in the Plastic Molding process group, except that the volume of the molded subcomponents is used in place of the volume of the whole part. It depends on the following:

- Molded Subcomponent Volume: sum of the values of the **Volume** property for all Subcomponents whose **Is Molded** property is true.
- Cost per Volume: this is the product of the values of the material properties **Unit Cost** and **Density** for the current material (listed in the Material Selection dialog, which is available from the Production Scenario tab of the Cost Guide).
- Utilization: see [IM Material Utilization](#) in the Plastic Molding chapter.
- Final yield: see [Yields for Assembly Molding](#).

Labor Cost = Labor Time * Labor Rate / Final Yield

Labor cost depends on the following:

- Labor time (see formula)
- Labor rate (specified by the machine property **Labor Rate**)
- Final yield (see [Yields for Assembly Molding](#))

Labor Time = Cycle Time * Number of Operators * Labor Time Standard

Labor time is the product of the following:

- Cycle time (see formula)
- Number of operators: specified by the machine property **Number of Operators**.
- Labor time standard: specified as the machine property **Labor Time Standard**. This multiplier is used to account for otherwise unaccounted for factors that affect labor time, such as operator fatigue or time spent by the operator for cleaning or maintenance.

Cycle Time = Process Time * Cycle Time Adjustment Factor

Cycle time is the product of the following

- Process time: see formula.
- Cycle time adjustment factor: specified by the cost model variable `cycleTimeAdjustmentFactor` (1 in starting point VPEs). Administrators can customize this value in order to globally adjust cycle times for Assembly Molding.

Process Time

The method of process-time calculation depends in the **Table Configuration** of the current Insert Injection Molding machine.

Process Time No Table =

$$\frac{(\text{Pick and Place Non-idle Time} + \text{Insert Injection Molding Non-idle Time})}{\text{Number of Cavities}}$$

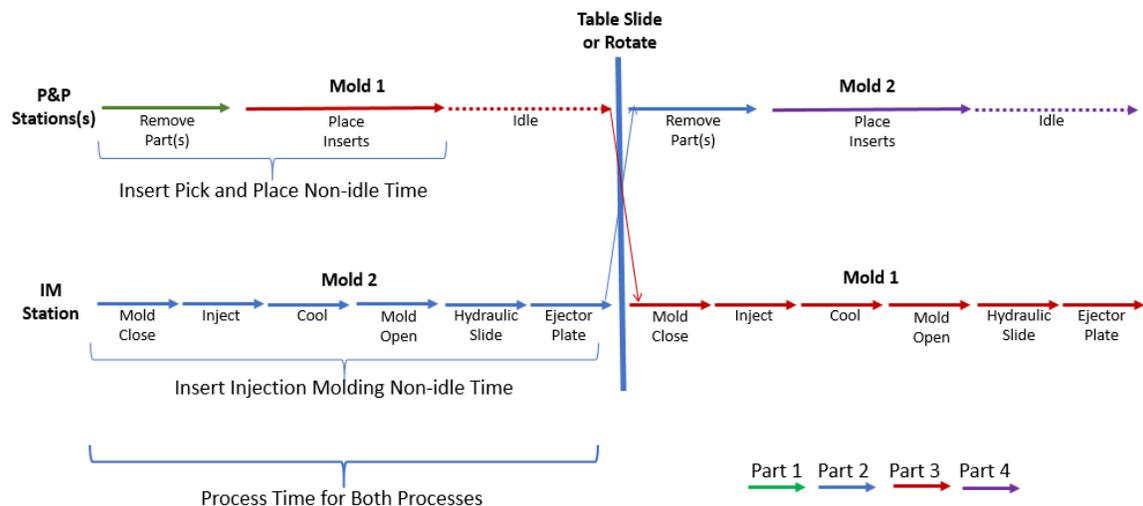
If the machine selected for Insert Injection Molding has no table (as specified by the machine property **Table Configuration**), The Insert Injection Molding machine is idle during Pick and Place tasks. In this case, Insert Pick and Place process time depends on the following:

- Pick and Place non-idle time (see formula)
- Insert Injection Molding non-idle time (see formula)
- Number of mold cavities (see [Number and Layout of Mold Cavities](#) in the Plastic Molding chapter)

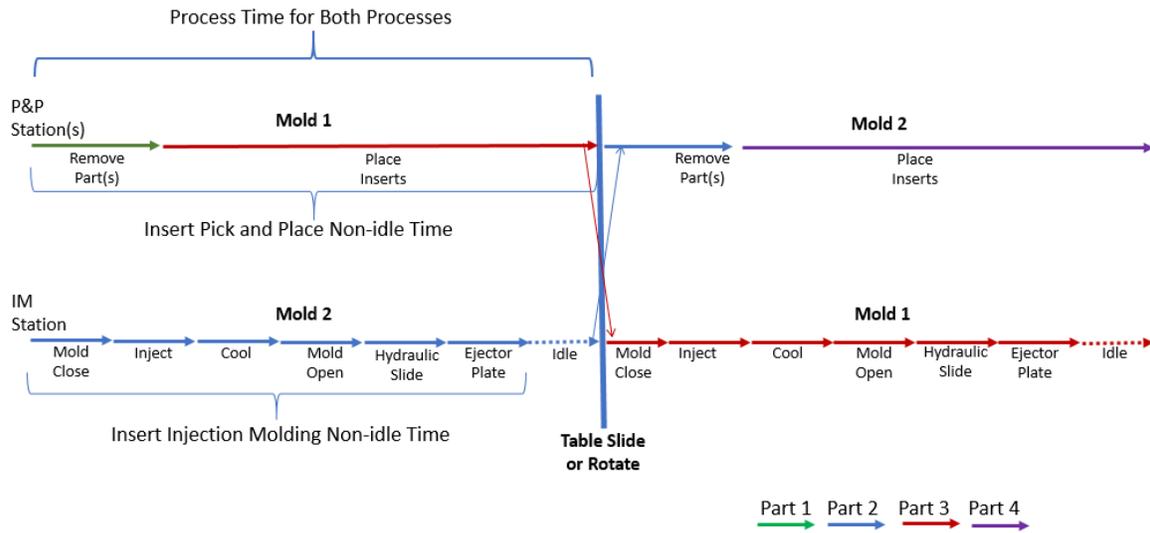
Process Time Shuttle or Rotary =

$$\frac{\max(\text{Pick and Place Non-idle Time}, \text{Insert Injection Molding Non-idle Time})}{\text{Number of Cavities}}$$

If the machine selected for Insert Injection Molding has a rotary or shuttle table (as specified by the machine property **Table Configuration**), Insert Pick and Place operators can work with one or more lower tools (removing parts and then placing inserts) while Insert Injection Molding operators use another lower tool together with the upper tool (for injection and cooling). Pick and Place Operators are idle during a cycle only if injection and cooling takes longer than removing parts and placing inserts. In this case, the two parallel streams of activity might be represented as follows:



On the other hand, if removing parts and placing inserts takes longer than injection and cooling, Insert Injection Molding operators are idle during each cycle. In this case, the two parallel streams of activity might be represented as follows:



For manual loading (see [Manual or Robotic Loading](#)), increasing the number of Insert Pick and Place operators is assumed to decrease the total time required to place inserts.

Insert Pick and Place process time depends on the following:

- Pick and Place non-idle time (see formula)
- Insert Injection Molding non-idle time (see formula)
- Number of mold cavities (see [Number and Layout of Mold Cavities in the Plastic Molding](#) chapter)

**Pick and Place Non-idle Time =
Part Removal Time +
((Child Operation Times * Number of Cavities) / Number of Operators)**

Pick and Place non-idle time is the time required to remove parts from one mold and then place all inserts into it. It depends on the following:

- Part removal time: depends on how the setup option [Part Eject Method](#) is set:
 - **Robotic:** part removal time is the value of the cost model variable **robotGrabTime** (6 seconds in starting point VPEs).
 - **Manual:** part removal time is the value of the cost model variable **manualGrabTime** (8 seconds in starting point VPEs).
 - **Gravity:** part removal time is the value of the cost model variable **gravityDropTime** (1.25 seconds in starting point VPEs).

The default in starting point VPEs is **Manual**. Administrators can customize the default with the cost model variable **ejectMethod**.

Note that, with multiple cavities, it is assumed that all parts are removed at once, regardless of eject method.

- Child operation cycle times for Insert Pick and Place (see [Insert Pick and Place Operation Formulas](#))

- Number of Mold Cavities (see [Number and Layout of Mold Cavities](#) in the Plastic Molding chapter)
- Number of operators for Pick and Place: by default, this is specified by the machine property **Number of Operators**. Users can override the default with the setup option [Number of Operators](#).

**Insert Injection Molding Non-idle Time =
 Mold Close Time +
 Injection Time +
 Cool Time +
 Hydraulic Slide Time +
 Mold Open Time +
 Ejector Plate Time**

Insert Injection Molding non-idle time is the sum of the following:

- Mold close time (see [Insert Injection Molding Formulas](#))
- Injection time (see [Insert Injection Molding Formulas](#))
- Cool time (see [Insert Injection Molding Formulas](#))
- Hydraulic slide time (see [Insert Injection Molding Formulas](#))
- Mold open time (see [Insert Injection Molding Formulas](#))
- Ejector plate time (see [Insert Injection Molding Formulas](#))

Injection Time = ((Number of Cavities * Part Volume) + Runner Volume) / Adjusted Injection Rate

Injection time is function of the following:

- Number of cavities (see [Number and Layout of Mold Cavities](#) in the Plastic Molding chapter)
- Part volume (obtained from GCD extraction)
- Runner volume (see [Runner Volume and Runner Area for Assembly Molding](#))
- Adjusted injection rate (see formula below)

Adjusted Injection Rate = Injection Rate * Injection Rate Multiplier

Adjusted injection rate is the product of the following:

- Injection rate: specified by the machine property **Injection Rate**.
- Injection rate multiplier: specified by the cost model variable **injectionRateMultiplier** (0.25 in starting point VPEs).

Cool Time = 0 – ((Nominal Wall Thickness²) / (2 * π * Thermal Diffusivity) * ln((π/4) * (Eject Deflection Temperature – Mold Temperature) / (Melting Temperature – Mold Temperature)))

Cool time is a function of the following:

- Nominal wall thickness: see [Nominal Wall Thickness](#).
- Thermal diffusivity: see formula, below.

- Eject deflection temperature: temperature at which the part can be ejected from the mold without deformation, specified by the material property **Eject Deflection Temp**.
- Melting temperature: specified by the material property **Melting Temp**.
- Mold temperature: required temperature of the mold to support proper molten polymer flow. This is specified by the material property **Mold Temp**, increased by the amount specified by the cost model variable **defaultMoldTemperatureIncrease** (0 in starting point VPEs) or by the override specified by the user with the setup option Local Mold Temperature Increase—see [User Inputs for Plastic Molding](#).

Thermal Diffusivity = Thermal Conductivity / (Density of Melt * Specific Heat)

This is the thermal diffusivity of the current material, in mm²/s. The value is converted from m²/s to mm²/s so that it can be used in the Cool Time formula. The value in m²/s is determined according to this formula by using the following:

- Thermal conductivity: this is the thermal conductivity of the current material, specified in watt/m°C by the material property **Thermal Conductivity of Melt**.
- Density of melt: this is the melt density of the current material, specified in kg/m³ by the material property **Density of Melt**.
- Specific heat: this is the specific heat of the current material, specified in joule/g°C by the material property **Specific Heat of Melt**, and converted to joule/kg°C for use in this formula.

Note: Versions of aPriori prior to 2019 R2 used a value for thermal diffusivity that was provided by the material property **Thermal Diffusivity**, rather than computing it from thermal conductivity, density of melt, and specific heat. The cost model will continue to use the material property **Thermal Diffusivity**, if the new material properties **Thermal Conductivity of Melt**, **Density of Melt**, and **Specific Heat of Melt** are not provided; however aPriori recommends that you update older VPEs to use the new properties, as they are reliably found on spec sheets, while thermal diffusivity generally is not.

Nominal Wall Thickness = (2 * Average Wall Thickness + Maximum Wall Thickness) * 1.25/3

Nominal wall thickness is calculated by default, but can be specified by the user with the process-level setup option **Nominal Wall Thickness** (0.10-15.00 millimeters). If calculated, the following formula is used:

Nominal wall thickness is a linear combination of the following:

- Part average wall thickness (obtained from GCD extraction)
- Part maximum wall thickness (obtained from GCD extraction)

This value is bounded above by part maximum thickness.

Mold Open Time = Travel Distance / Max Machine Velocity

Mold open time depends on the following:

- Travel distance: see Travel Distance, below.

- Max machine velocity: see formula.

Travel Distance

Travel distance for mold open or close is generally 3 or 4 times the part height:

- If the setup option **Part Eject Method** is set to **Manual** (the default in starting point VPEs) or **Gravity**, the travel distance is generally the product of part height and the cost model variable **nominalHeightFactor** (3 in starting point VPEs):

$$\text{Travel Distance} = \text{Part Height} * \text{Nominal Height Factor}$$

To accommodate small parts, this value is bounded below by the product of **smallHeightPartFactor** (1.1 in starting point VPEs) and the length of the plastic forming region (PFR--see [Dimensions of the Plastic Forming Region](#) in the Plastic Molding chapter):

$$\text{Travel Distance} = \text{PFR Length} * \text{Small Height Factor}$$

In starting point VPEs, this applies when the part height is less than roughly 1/3 of the PFR length.

- If the setup option **Part Eject Method** is set to **Robotic**, the travel distance is generally the product of the following:
 - Part height
 - Sum of the cost model variables **nominalHeightFactor** (3 in starting point VPEs) and **roboticClearanceFactor**(1 in starting point VPEs)

$$\text{Travel Distance} = \text{Part Height} * (\text{Nominal Height Factor} + \text{Robotic Clearance Factor})$$

To accommodate small parts, this value is bounded below by the product of the following:

- Length of the plastic forming region (PFR--see [Dimensions of the Plastic Forming Region](#) in the Plastic Molding chapter)
- Sum of the cost model variables **smallHeightPartFactor** (1.1 in starting point VPEs) and **roboticClearanceFactor** (1 in starting point VPEs)

$$\text{Travel Distance} = \text{PFR Length} * (\text{Small Height Factor} + \text{Robotic Clearance Factor})$$

In starting point VPEs, this applies when the part height is less than roughly 1/2 the PFR length.

See also [Part Eject Method](#).

Max Machine Velocity = (Machine Max Stroke Length * 2) / Dry Cycle Time

The speed of travel during mold open and close is derived from the following:

- Machine max stroke length: for Vertical machines (see [Insert Injection Molding Machine Orientation](#)), this is the value of the machine property **Dry Cycle Stroke**. For Horizontal machines, see formula.
- Dry cycle time: specified by the machine property **Dry Cycle Time**.

**Machine Max Stroke Length for Horizontal Machines =
Dry Cycle Stroke Factor * Max Tie Bar Distance**

- Dry cycle stroke factor: this is the fraction of the maximum tie bar distance that equals the stroke length. The fraction is specified by the cost model variable **dryCycleStrokeFactor** (0.7 in starting point VPEs—see the Euromap 6 technical recommendation).
- Max tie bar distance: this the larger of the machine properties **Tie Bar Distance, H** and **Tie Bar Distance, V**.

Hydraulic Slide Time = (Hydraulic Slide Length / Slide Cycle Rate) * 2

A slide for a given undercut feature is required to be hydraulic (as opposed to mechanical) if the platen movement required to clear the mechanical slide from the undercut exceeds the mold open stroke. The presence of hydraulic slides contributes to the total ejection time because, unlike mechanical slides, hydraulic slides are retracted only after the mold is opened.

Hydraulic slide time depends on the following:

- Hydraulic slide length: this is 0 if hydraulic slides are unnecessary. If hydraulic slides are necessary, the hydraulic slide length is the maximum undercut depth plus some clearance (5mm if there are multiple cavities, 0.5 inch otherwise).
- Cycle rate per slide: this is the rate at which the hydraulic slides can move, specified by the cost model variable **slideCycleRate** (100mm per second in starting point VPEs).

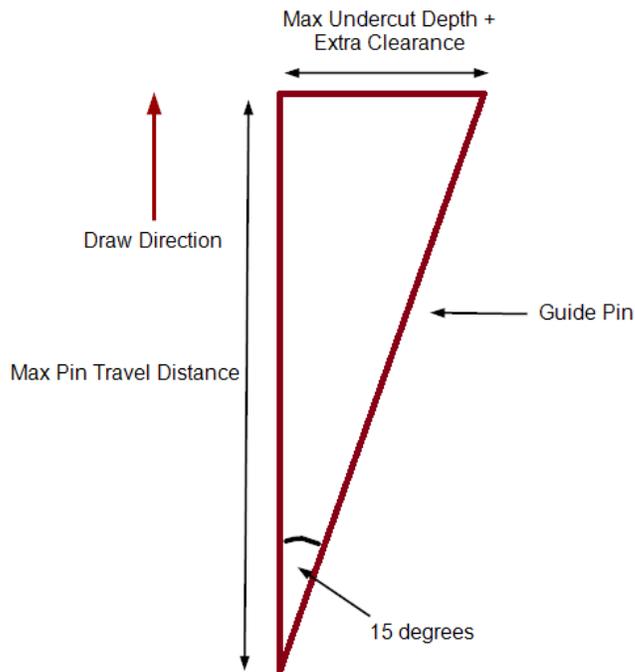
Hydraulic slides are necessary if and only if the following condition holds:

$$\text{Max Pin Travel Distance} > \text{Machine Opening Stroke}$$

Here, Machine Opening Stroke is the value of the machine property **Opening Stroke**.

Max Pin Travel Distance is the distance along the draw direction that the platen would have to travel in order to retract a mechanical slide from the part's deepest undercut. The cost model assumes that a retracting mechanical slide is guided by a pin that makes an angle of 15 degrees with the draw direction. If U is the maximum undercut depth (perpendicular to the draw direction) plus clearance (5mm if there are multiple cavities, 0.5 inch otherwise), then the required platen motion along the draw direction is $U/\tan(15)$:

$$\text{Max Pin Travel Distance} = (\text{Max Undercut Depth} + \text{Extra Clearance}) / \tan(15)$$



If the motion required for a mechanical slide (Max Pin Travel Distance) exceeds the value of the machine property **Opening Stroke**, then hydraulic slides are necessary for the part.

Ejector Plate Time = (Part Height * Ejector Distance Factor) / Max Machine Velocity

Ejector plate time depends on the following:

- Part height: determined by geometry extraction. Part height is measure along the draw direction.
- Ejector distance factor: this is the multiple of part height that equals the distance an ejector pin should move in order to eject the part. It is specified by the cost model variable **ejectorDistanceFactor** (3 in starting point VPEs).
- Max machine velocity: see formula.

Mold Close Time = Travel Distance / Max Machine Velocity

Mold close time depends on the following:

- Travel distance: see Travel Distance, above.
- Max machine velocity: see formula.

Runner Volume and Runner Area for Assembly Molding

As with Plastic Molding, Assembly Molding's runner system model is used to calculate to important quantities:

- Runner area: area of the projection of the runners onto the parting plane. This quantity plays a role in the calculation of required clamp force and required shot size, which are used in [Machine Selection for Insert Injection Molding](#).
- Runner volume: total volume of all runners. This quantity plays a role in the calculation of material utilization and injection time. See [IM Material Utilization](#) in the Plastic Molding chapter and [Insert Injection Molding Formulas](#).

The section [Runner System Model](#) describes in detail the model of the runner system used by the Plastic Molding process group. The Assembly Molding process group uses the same model, modified to accommodate intra-part, inter-component runners, that is, runners between the plastic Subcomponents of a part.

Compared to runner area as computed for the Plastic Molding process group, runner area for Assembly Molding is greater by the following quantity:

$$\text{Runner Area Supplement} = \text{Number of Cavities} * \text{Inter-component Runner Length Per Part} * \text{Inter-component Runner Diameter}$$

And compared to runner volume as computed for the Plastic Molding process group, runner volume for Assembly Molding is greater by the following quantity:

$$\text{Runner Volume Supplement} = \text{Number of Cavities} * \text{Inter-component Runner Length per Part} * \pi * (\text{Inter-component Runner Diameter}/2)^2$$

These quantities are a function of the following:

- Inter-component runner length per part: this is the total length of the runners between the subcomponents of given part. It is assumed to be half the length of the diagonal of the part's bounding rectangle (in a plane normal to the draw direction):

$$\text{Inter-component Runner Length Per Part} = \text{sqrt}(\text{Part Length}^2 + \text{Part Width}^2) / 2$$
- Inter-component Runner Diameter: the diameter of each inter-component runner is assumed to be the same as the diameter of the runner branch that feeds a single cavity. This value is 25% greater than the part's **Max Thickness** (bounded below by the value of the cost model variable **minRunnerDia**—2.032mm in starting point VPEs).
- Number of cavities: see [Number and Layout of Mold Cavities](#) in the Plastic Molding chapter.

See the formulas for **Runner Area** and **Runner Volume** in the [Runner System Model](#) section of the Plastic Molding chapter.

Yields for Assembly Molding

These formulas are used by all the processes in this process group.

$$\text{Final Yield} = \text{Final Output Volume} / \text{Input Volume}$$

Final yield affects material, labor, and overhead costs per part. It is the fraction of parts created by this process in the current production scenario that will survive as good parts once any secondary processes are completed. That is, final yield is the fraction of parts

created by this process that are *not* discarded as scrap parts, either by this process or by a downstream process. Final yield depends on the following:

- Final Output Volume (product of the annual volume and number of production years, specified in the Production Scenario screen of the Cost Guide)
- Input volume (see the formula below). This is the total number of parts produced by this process, including all parts discarded as scrap from this process or downstream processes.

Input Volume = Local Output Volume + Number of Scrap Parts for This Process

Input volume is the total number of parts produced by this process in the current scenario, including all parts discarded as scrap from this process or downstream processes. It is the sum of the following:

- Local output volume (see the formula below). This is the number of parts produced by this process, excluding parts discarded as scrap by this process, but including parts that are discarded as scrap by downstream processes.
- Number of scrap parts for this process (see the formula below)

Local Output Volume = Final Output Volume + Number of Scrap Parts Downstream

Local output volume is the number of parts produced by this process in the current scenario, excluding parts discarded as scrap by this process, but including parts that are discarded as scrap by downstream processes. It is the sum of the following:

- Final output volume (product of volume and number of production years, specified in the Production Scenario screen of the Cost Guide)
- Number of Scrap Parts Downstream. This is the number of parts discarded as scrap by downstream processes.

Number of Scrap Parts for This Process = (Local Output Volume / Good Part Yield) – Local Output Volume

Number of scrap parts for this process is the number of parts produced by this process in the current scenario that are discarded as scrap by this process, before any downstream process is performed on them. It is a function of the following:

- Local output volume (see the formula above)

Good part yield (specified by the machine property **Good Part Yield**). This is the fraction of parts produced by this process that are not discarded as scrap by this process but may be discarded as scrap by downstream processes.

User Inputs for Assembly Molding

The following sections cover setup options provided by the Assembly Molding process group:

- Top-Level Setup Options
- Process-level Insert Pick and Place Options
- Operation-level Insert Pick and Place Options
- Insert Injection Molding Options

Top-Level Setup Options

Operation assignment fails for GCDs with insufficient draft or with edge radii that are too small, provided that you enable the relevant checks by setting one or both of the following setup options:

- Draft Angle Check
- Minimum Edge Radius Check

The following setup options enable wall-thickness feasibility checks at the process level:

- Minimum Wall Thickness Check
- Maximum Wall Thickness Check

Minimum Wall Thickness Check

Minimum wall thickness checking is disabled by default. If this setup option is enabled, and the wall thickness of a GCD is less than the relevant minimum, Insert Injection Molding is considered infeasible, and costing fails. See [Process Feasibility for Insert Injection Molding](#).

Maximum Wall Thickness Check

Maximum wall thickness checking is disabled by default. If this setup option is enabled, and the wall thickness of a GCD is greater than the relevant maximum, Insert Injection Molding is considered infeasible, and costing fails. See [Process Feasibility for Insert Injection Molding](#).

Draft Angle Check

Draft angle checking is disabled by default. If this setup option is enabled, and the draft angle of a GCD is less than the relevant minimum, operation assignment fails for that GCD. See [Operation Assignment for Insert Injection Molding](#).

Minimum Edge Radius Check

Edge radius checking is disabled by default. If edge radius checking is enabled, and the edge radius of a GCD is less than the relevant minimum, operation assignment fails for the GCD. See [Operation Assignment for Insert Injection Molding](#).

Process-level Insert Pick and Place Options

The Pick and Place process provides the following setup options:

- Manual or Robotic Loading
- Number of Operators

Manual or Robotic Loading

Insert Pick and Place operations can be performed either manually or robotically (see [Machine Selection for Insert Pick and Place](#)). By default in starting point VPEs, the

loading method is **Manual**. Administrators can customize the default with the cost model variable **loadManualOrRobotic**.

With this setup option, users can override the default on a per-part basis, and specify one of the following:

- **3-axis**: loading is performed by a 3-axis robot.
- **6-axis**: loading is performed by a 6-axis robot.
- **Manual**: loading is performed manually.

Number of Operators

By default, the number of Insert Pick and Place operators is specified by the machine property **Number of Operators**. With this setup option, users can override the default and specify a different number of operators, including a fractional number of operators.

For manual loading (see [Manual or Robotic Loading](#)), increasing or decreasing the number of operators is assumed to speed up or slow down (respectively) the placing of inserts. That is, labor time is independent of number of operators, and process time is inversely proportional to the number of operators (see [Insert Pick and Place Process Formulas](#)).

Operation-level Insert Pick and Place Options

Insert Pick and Place operations provide the following options, which can be set on a per-GCD basis for non-molded Subcomponents:

- **Base Load Time**
- **Load time multiplier for handling difficulties**
- **Load time multiplier for insertion difficulties**

Base Load Time

This is the time it takes to pick one non-molded subcomponent of a part and place into the mold or onto an action mechanism. By default, load time is looked up by part weight and load method (see [Manual or Robotic Loading](#) in the lookup table **tblComponentLoadTime**). For Manual Load, this base load time is adjusted based on any special handling and/or insertion difficulties. See [Insert Pick and Place Operation Formulas](#).

With this setup option, users can override the default on a per-subcomponent basis, and specify the base load time explicitly.

Load time multiplier for handling difficulties

This is a factor that accounts for any special handling difficulties, such as those caused by component nesting, stickiness, or fragility.

By default, no special handling difficulties are assumed; that is, this factor is 1, by default. See [Insert Pick and Place Operation Formulas](#).

With this setup option, users can override the default on a per-subcomponent basis, and do one of the following:

- Set the factor to a standard value (specified by the cost model variable **handlingMultiplier**--1.15 in starting point VPEs).
- Specify the factor explicitly.

Load time multiplier for insertion difficulties

This is a factor that accounts for any special insertion difficulties, for example, difficulties with alignment and positioning due to obstructed access, obstructed vision, or lack-of-alignment features such as chamfers and lead-ins.

By default, no special insertion difficulties are assumed; that is, this factor is 1, by default. See [Insert Pick and Place Operation Formulas](#).

With this setup option, users can override the default on a per-subcomponent basis, and do one of the following:

- Set the factor to a standard value (specified by the cost model variable **handlingMultiplier**--1.12 in starting point VPEs).
- Specify the factor explicitly.

Insert Injection Molding Options

The Insert Injection Molding process provides the same setup options as Injection Molding in the Plastic Molding process group (see [User Inputs for Plastic Molding](#)). It also provides the following additional setup options:

- [Insert Injection Molding Machine Orientation](#)
- [Vertical Table Configuration](#)
- [Number of Mold Tools Per Table](#)
- [Insert Retention Cost](#)
- [Part Eject Method](#)

Note that for some of the setup options provided by both Insert Injection Molding and Plastic Molding (such as **Number of Small Inserts**), the names and descriptions use "Insert" to mean mold insert (such as a grill insert) rather than non-molded Subcomponent.

Note also that, in the case of a part with multiple molded Subcomponents, the setup options use the term 'cavity' to refer to the mold cavity for the entire molded portion of the Assembly Molding part, rather than to the cavity for a single molded Subcomponent. So, for example, 'Number of Mold Cavities' refers to the number of top-level Insert Molding parts that are handled by the mold.

Insert Injection Molding Machine Orientation

Each Insert Injection Molding machine has one of the following orientations:

- **Vertical Machines:** the draw direction is vertical. These machines *cannot* use the [Garvity Part Eject Method](#).

- Horizontal machines: the draw direction is horizontal. These machines can have *neither a Rotary nor a Shuttle Vertical Table Configuration*.

Machine orientation (**Horizontal** or **Vertical**) is specified by the machine property **Orientation**.

By default in starting point VPEs, machine selection considers only Vertical machines. Administrators can customize the default with the cost model variable **insertInjectionMoldingMachineOrientation**. Users can override the default on a per-part basis with this setup option. Select one of the following:

- **Vertical** (default in starting point VPEs): machine selection considers only vertical machines.
- **Horizontal**: machine selection considers only horizontal machines.
- **No Preference**: machine selection considers both vertical and horizontal machines.

Part Eject Method

By default in starting point VPEs, the part is removed from the mold manually. Administrators can customize the default with the cost model variable **ejectMethod**. Users can override the default on a part-by-part basis with this setup option. Select one of the following:

- **Robotic**: part removal time is the value of the cost model variable **robotGrabTime** (6 seconds in starting point VPEs).
- **Manual**: part removal time is the value of the cost model variable **manualGrabTime** (8 seconds in starting point VPEs).
- **Gravity**: part removal time is the value of the cost model variable **gravityDropTime** (1.25 seconds in starting point VPEs). *Note*: if you select this option, machine selection considers only horizontal machines.

See Part Removal Time in [Insert Injection Molding Formulas](#).

Note: Vertical machines do not support **Gravity**-drop part removal. If [Insert Injection Molding Machine Orientation](#) is set to **Vertical**, **Part Eject Method** must be set to **Manual** (the default in starting point VPEs) or **Robotic**; otherwise machine selection fails.

Vertical Table Configuration

By default in starting point VPEs, [Machine Selection for Insert Injection Molding](#) considers only machines with **No table**. Administrators can customize the default behavior with the cost model variable **verticalTableConfiguration**, and specify that machine selection should consider only machines with a **Shuttle** table or only machines with a **Rotary** table, by default. With this setup option, users can override the default on a part-by-part basis.

A vertical machine has one of the following table configurations (indicated by the machine property **Table Configuration**):

- **Shuttle**: has two molds and moves side-to-side to position a given mold for insert pick and place or for injection molding.
- **Rotary**: has two or more molds, and rotates to position each for pick and place or injection molding.

- **No table:** handles only one mold at a time.

A rotary or shuttle table allows for two molds to be processed in parallel: pick and place is performed for a part or parts made in one mold, while injection molding is performed with the other mold. Using a machine with a shuttle or rotary table can reduce cycle time and labor time—see [Insert Pick and Place Operation Formulas](#).

Note: Horizontal machines support only the **No table** configuration. If you select **Horizontal** for [Insert Injection Molding Machine Orientation](#), [Vertical Table Configuration](#) must be set to **No table** (the default in starting point VPEs); otherwise machine selection fails.

Number of Mold Tools Per Table

By default in starting point VPEs, for machines with a shuttle or rotary table (see [Machines for Assembly Molding](#)), tooling is assumed to include two mold lower halves and one mold upper half. This allows one lower tool to be loaded while the other (together with the tool upper half) is injected (see [Formulas for Assembly Molding](#)). Administrators can customize the default number of lower tools with the cost model variable **defaultNumMoldToolsPerTable**. Users can override the default on a per-part basis with this setup option. This setting drives tooling costs.

Insert Retention Cost

By default, the cost model assumes negligible cost for any retention tools that are required to hold non-bundled inserts in place in the mold prior to injection. In addition, the cost model assumes that a bundled insert can slide over or into its associated slide or lifter, and that no additional tool is needed to ensure that the insert is retained in place. (See [Geometric Cost Drivers for Assembly Molding](#) for information on bundled versus non-bundled inserts.)

With this setup option, users can override the default, and specify the cost for retention tools over and above the cost for slides and lifters. This cost contributes to hard tooling cost (see [Tooling for Assembly Molding](#)).

Bar & Tube Fabrication Process Group

This section describes the costing details and inputs available for the Bar & Tube Fabrication process group.

This chapter includes the following topics:

- Cost Model Overview
 - Costing Flow
 - Cost Algorithms and Calculations
 - User Inputs
 - Process Group Site Variables
 - Process Defaults and Thresholds
-

Cost Model Overview

This overview section summarizes assumptions and limitations of the following aspects of the model:

- Bar & Tube General Process
- Part Geometry
- Materials and Stock Forms
- Machines
- Tooling

Bar & Tube General Process

The **Bar&Tube Fab** process group applies to parts created from bar, tube, angle, channel, and I-beam stock, as well as round tubes created from sheet stock with Roll Bending.

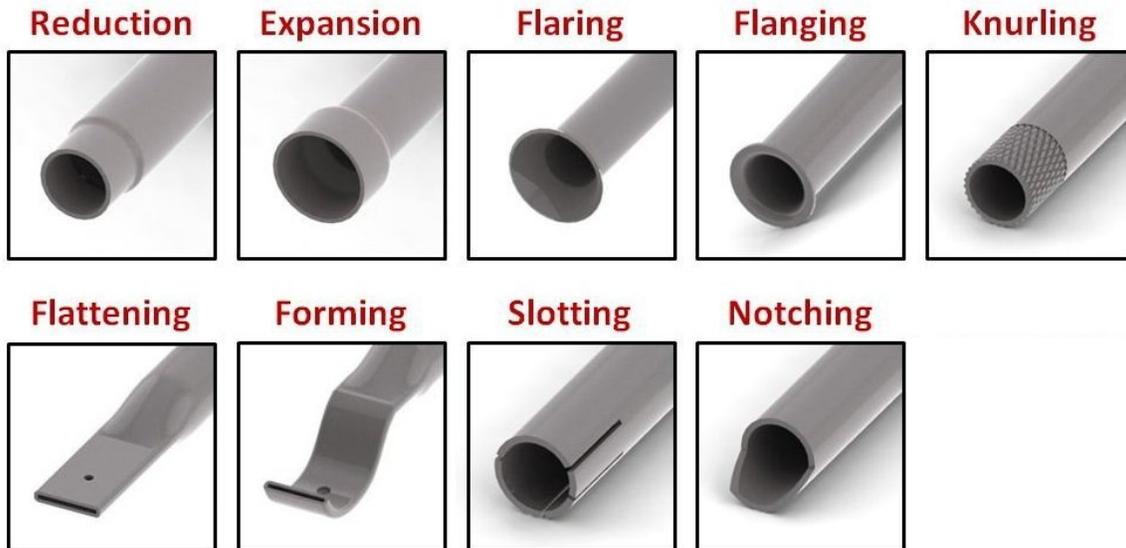
Process Types

The model supports various alternatives for the following types of processes used with bar, tube, angle, channel, and I-beam stock:

- Cutting and trimming: cutting a piece of stock to length or trimming off unneeded material (such as extra trim material used in a previous process as a gripping surface for a bending machine). Cutting and trimming includes both straight and miter (angled) cuts using the following processes:
 - **Band Saw**
 - **Circular Saw**
 - **Reciprocating Saw**
 - **Shear**
 - **Tube Laser** (for cutting tubes, angle bars, or channel bars; also used for hole making)
- Hole making: creating a hole of a given size or shape by using one of the following processes:
 - **Punching** (using a standard die set)
 - **Tube Laser** (for simple or complex holes in tubes, angle bars, or channel bars; also used for cutting)
- Bending: creating a bend in a tube, bar, or I-beam using one of the following processes:
 - **Rotary Draw Bending**
 - **Compression Bending** (ram bending)
 - **Bar Bend Brake**
- Forming: changing the shape of an end of a bar or tube, or expanding or reducing a segment of it. Forming includes the following processes:
 - **Reduction**
 - **Expansion**
 - **Flaring**
 - **Flanging**

- Flattening
- Forming
- Slotting
- Notching
- Knurling

Supported forming processes are illustrated below.



Additionally, aPriori supports plate rolling from sheet stock using 2-, 3-, or 4-Roll Bending. Currently only round tubes with 360° bends are supported. (Non-360° Roll Bending is supported by the Sheet Metal process group. See *Sheet Metal—Soft Tooling*.)

Plate rolling consists of the following types of processes:

- Cutting and hole-making: in this case, one of the following processes:
 - Sheet Laser Cut
 - Sheet Plasma Cut
 - Sheet OxyFuel Cut
- Bending:
 - 2-, 3-, or 4-Roll Bending

If you have licensed the appropriate modules, your routing can include optional machining, turning, heat treatment, surface treatment, and packaging processes.

See [Process-level Routing](#) and [Process-level Feasibility](#) for more information.

Process Limitations:

The model is well suited for parts for heavy equipment, furniture, and small vehicles. It is not well suited for high precision components or components that serve to carry liquid or gas.

Other limitations include the following:

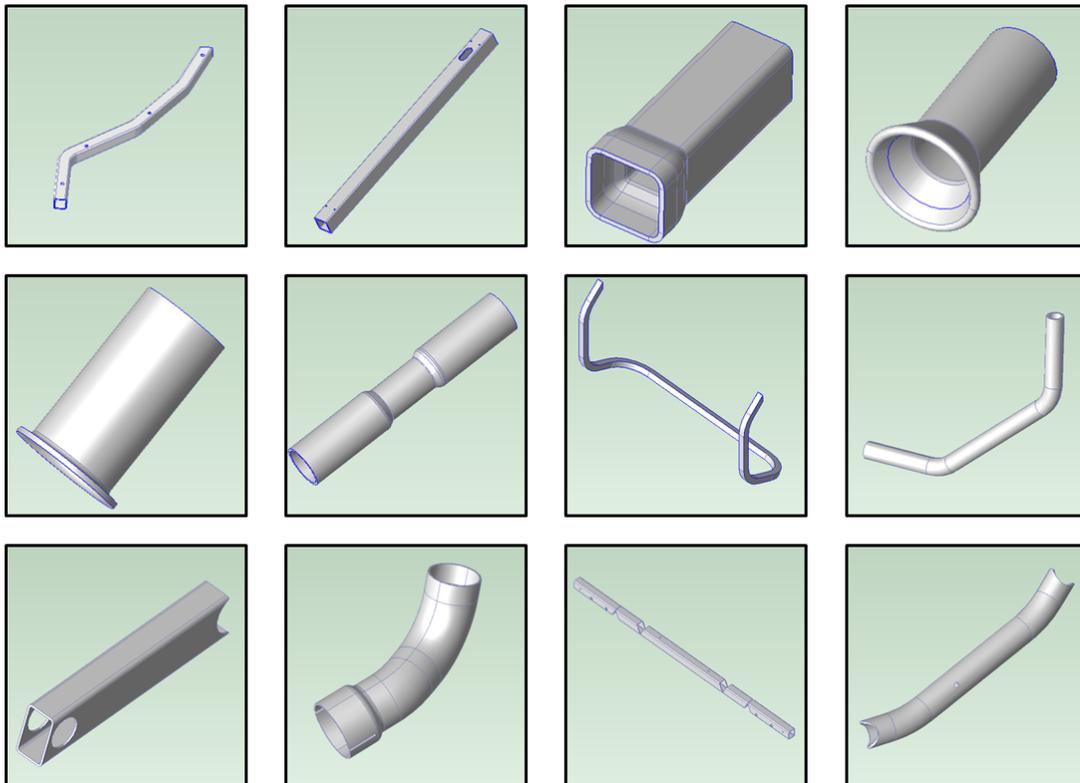
- Limited automatic detection of end forms. Most have to be manually included by the user
- No support for custom stock forms or the ability to accept a generic stock form (although, as with other process groups, virtual stock is supported)
- Limited support for specialized, multi-process machines
- No support for Roll Bending bends less than 360°
- No abrasive wheel support for sawing
- Limited support for multiple punches at once
- No support for special purpose bar and tube machines that use off-the-shelf punch heads but are custom configured for high volume production

In addition, the model does not support the following processes:

- 3D laser cutting
- Roll forming for standard and custom stock forms

Part Geometry

Geometry recognition requires parts to be manufactured from the list of available material stock forms (See *Materials*). If the stock form is not automatically determined, users can specify the material stock form and stock orientation by using the Stock Form and Alignment tool. Parts can have holes, bends, expansions, reductions, flanges, and flares. A small selection of example parts is shown below.



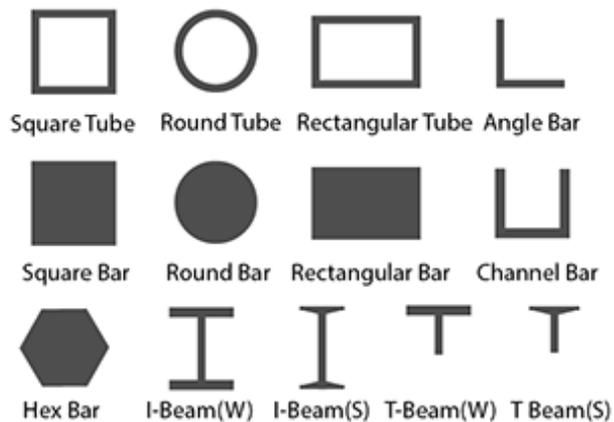
See [GCD Extraction](#) for more information.

Materials and Stock Forms

Supported stock forms include the following:

- Bar stock:
 - Square
 - Round
 - Rectangular
 - Hex
 - Angle
 - Channel (regular and structural)
- Tube stock:
 - Square
 - Round
 - Rectangular
- I-Beam stock:
 - I-Beam (W)
 - I-Beam (S)
- I-Beam stock:
 - T-Beam (W)
 - T-Beam (S)

Bar & Tube Stock



In addition, the process group supports extruded stock—see [Extrusion GCDs](#).

Supported materials include the following (but note that not all materials support all stock forms):

- Aluminum: ANSI 6061, 6060 T6
- Copper: UNS C11000
- Galv. steel: HR AISI 1010, HR AISI 1012, HR AISI 1020
- Hastelloy: C-276, X
- Inconel: 625, 718

- Stainless steel: AISI 304, AISI 316, AISI 316L
- Steel: CR AISI 1010, CR AISI 1012, CR AISI 1020, HR AISI 1010, HR AISI 1012, HR AISI 1020, HR ASTM A36
- Titanium: Ti-5Al-2.5Sn, Ti-6Al-4V

Material composition details include the following:

- Angle Bar Unit Cost (USD / kg)
- Channel Bar Unit Cost (USD / kg)
- Hex Bar Unit Cost (USD / kg)
- I-Beam Unit Cost (USD / kg)
- Rectangular Bar Unit Cost (USD / kg)
- Rectangular Tube Unit Cost (USD / kg)
- Round Bar Unit Cost (USD / kg)
- Round Tube Unit Cost (USD / kg)
- Sheet Unit Cost (USD / kg)
- Square Bar Unit Cost (USD / kg)
- Square Tube Unit Cost (USD / kg)
- T-Beam Unit Cost
- Density (kg / m³)
- Shear Strength (MPa)
- Tensile Yield Strength (N / mm²)

Material details include equivalent DIN and EN name standards for use with regional VPEs.

Material stock details include the following:

- Stock Form
- Width (mm)
- Height (mm)
- Outside Diameter (mm)
- Inside Diameter (mm)
- Wall Thickness (mm)
- Length (mm)
- Unit Cost (USD / kg)

If you have licensed the Extrusions cost model, aPriori also attempts to recognize parts that can be manufactured from custom, extruded stock by using light-to-moderate material removal. See [Extrusion GCDs](#).

Machines

The following tables list important property value ranges of the machines supported for the various processes:

Band Sawing

Property	Low End	High End
Maximum Stock Diameter (mm)	330.0	635.0
Maximum Stock Height (mm)	330.0	670.0

Maximum Stock Width (mm)	330.0	1,270.0
--------------------------	-------	---------

Bar Bend Brake

Property	Low End	High End
Maximum Bend Length (mm)	415.0	4,267.2
Maximum Stock Width (mm)	510.0	3,810.0
Press Force (kN)	75.0	2,373.0

Bar Punching

Property	Low End	High End
Maximum Stock Diameter (mm)	24.7	76.0
Maximum Stock Length (mm)	6,098.0	10,000.0
Maximum Stock Thickness (mm)	6.5	38.1
Punch Force (kN)	485.0	2,132.0

Circular Sawing

Property	Low End	High End
Maximum Stock Diameter (mm)	119.0	399.0
Maximum Stock Height (mm)	28.0	150.0
Maximum Stock Width (mm)	119.0	399.0

Compression Bending

Property	Low End	High End
Maximum Tube Diameter (mm)	130	38.1

Expansion

Property	Low End	High End
Maximum Stock Diameter (mm)	76.2	203.2
Minimum Stock Diameter (mm)	12.7	76.2

Flanging

Property	Low End	High End
Maximum Stock Diameter (mm)	76.2	203.2
Minimum Stock Diameter (mm)	6.4	76.2

Flaring

Property	Low End	High End
Maximum Stock Diameter (mm)	76.2	203.2
Minimum Stock Diameter (mm)	6.4	76.2

Flattening

Property	Low End	High End
Maximum Stock Diameter (mm)	75.0	250.0
Minimum Stock Diameter (mm)	0.0	150.0

Forming (only one machine)

Property	
Maximum Stock Diameter (mm)	150.0
Minimum Stock Diameter (mm)	10.0

Knurling (only one machine)

Property	
Maximum Stock Diameter (mm)	150.0
Minimum Stock Diameter (mm)	5.0

Notching (only one machine)

Property	
Maximum Stock Diameter (mm)	150.0
Minimum Stock Diameter (mm)	10.0

Reciprocating Sawing

Property	Low End	High End
Maximum Stock Diameter (mm)	218.0	419.0
Maximum Stock Height (mm)	119.0	348.0
Maximum Stock Width (mm)	218.0	419.0

Rotary Draw Bending

Property	Low End	High End
Maximum Stock Length (mm)	2,260.6	4,114.8
Maximum Tube Diameter (mm)	34.9	254.0
Maximum Wall Thickness (mm)	1.7	9.5

Note that these machines include one that can accommodate small wire parts, with a minimum tube diameter of 5mm.

Shearing

Property	Low End	High End
Tonnage	45.4	136.1
Maximum Shear Length (mm)	254.0	609.6

Sheet Laser Cut

Property	Low End	High End
----------	---------	----------

Bed Length (mm)	1,524.0	6,096.0
Bed Width (mm)	3,048.0	4,876.0

Sheet OxyFuel Cut

Property	Low End	High End
Bed Length (mm)	1,524.0	6,096.0
Bed Width (mm)	1,219.0	3,048.0

Sheet Plasma Cut

Property	Low End	High End
Bed Length (mm)	1,250.0	7,315.2
Bed Width (mm)	1,219.20	3,225.8

Slotting (only one machine)

Property	
Maximum Stock Diameter (mm)	150.0
Minimum Stock Diameter (mm)	10.0

Tube Laser

Property	Low End	High End
Maximum Stock Diameter (mm)	120.0	302.0
Maximum Stock Length (mm)	2,000.0	8,500.0

2-Roll Bending

Property	Low End	High End
Roll Working Length (mm)	200.00	2050.00
Steel Thickness (mm)	1.5	5.0
Top Roll Diameter (mm)	88.90	420.00

3-Roll Bending

Property	Low End	High End
Roll Working Length (mm)	1500.00	3100.00
Top Roll Diameter (mm)	130.00	381.00
Weight (kg)	1025.00	7650.00
Min Multi Pass Diameter (mm)	333.2	1103.20
Max Multi Pass Thickness (mm)	2.00	19.05
Min Single Pass diameter (mm)	169.00	900.00
Max Single Pass Thickness (mm)	1.50	15.00

4-Roll Bending

Property	Low End	High End
Roll Working Length (mm)	2000.00	4089.00
Top Roll Diameter (mm)	152.40	730.00
Weight (kg)	2315.00	68000.00
Min Multi Pass Diameter (mm)	363.2	1614.00

Max Multi Pass Thickness (mm)	4.00	75.00
Min Single Pass diameter (mm)	224.00	1242.00
Max Single Pass Thickness (mm)	3.00	65.00

3-Roller Bending

Note: The 3-Roller Bending process is deprecated as of aPriori Release 2014R1 and will no longer be supported in a future release. It is replaced by the 2-, 3-, and 4-Roll Bending processes. More specifically, 3-Roller Bending was introduced in Cost Model Version 40 and is now replaced by the new Roll Bending models in Cost Model Version 60. If you currently use 3-Roller Bending, you should plan to move to one of the newer processes as soon as possible.

Property	Low End	High End
Maximum Sheet Thickness (mm)	69.9	152.4
Maximum Sheet Width (mm)	2032.0	4089.4
Minimum Sheet Thickness (mm)	6.4	25.4
Rolling Capacity (mm)	6.4	34.9
Roller Diameter (mm)	184.9	520.0

See [Machine Selection](#) for more information.

Tooling

No hard tooling is required for this process group, except for extrusions—see [Hard Tooling Cost](#). Programming cost is amortized over the total number of parts made.

Costing Flow

Before calculating costs in the cost taxonomy, aPriori performs tasks related to the following:

- GCD Extraction
- Feasibility and Routing

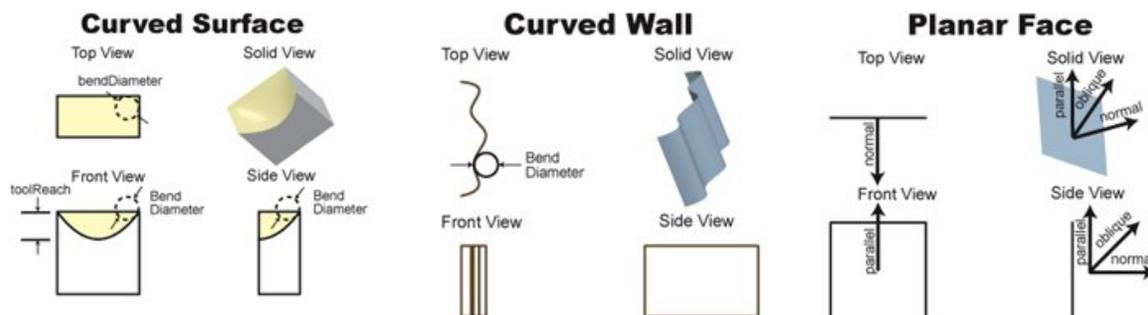
GCD Extraction

aPriori extracts the geometry of a CAD model in the form of geometric cost drivers (GCDs) that include Bends, Ends, and Forms, as well as Holes, Rings, Surfaces, and CrossSections. As usual, there is a special GCD, **Component**, that represents the part as a whole. Below are some of the important properties of each of these GCD types. Each GCD's units are shown in metric.

- **Component:**
 - Volume (mm³)
 - Surface Area (mm²)
 - Length, Width, and Height (millimeters)
 - Number of Surfaces
 - Min Thickness, Max Thickness, and Avg Thickness (millimeters)
 - Length Direction, Width Direction, and Height Direction: each of these is a unit vector, two of whose components are 0 (the other component

is 1 or -1). These vectors can be compared with the Direction vector of another GCD (such as a Perimeter or Setup Axis) in order to determine whether the GCD's direction is aligned with the part's length, width, or height.

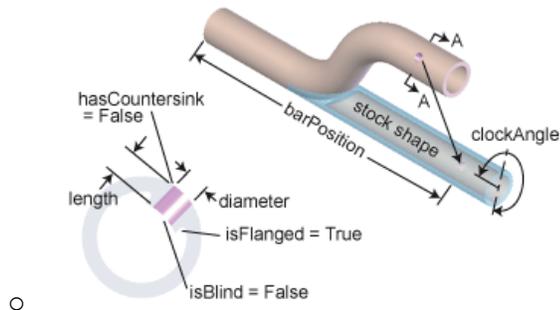
- **Cross Section:**
 - Area (mm²)
 - Height (millimeters)
 - Inside Diameter (millimeters)
 - Outside Diameter (millimeters)
 - Perimeter (millimeters)
 - Thickness (millimeters)
 - Width (millimeters)
 - Sheet Width (millimeters)
- **Surfaces (Curved Surface, Curved Wall, and Planar Face):**
 - Finished Area (mm²)
 - Bend Diameter (millimeters)
 - Perimeter (millimeters)
 - SER Length and SER Width (smallest enclosing rectangle dimensions in millimeters)
 - Corner Diameter (millimeters)
 - Inside Diameter (millimeters)
 - Number of Surfaces
 - Fillet Min Angle and Fillet Max Angle (degrees)
 - Round Radius (millimeters)
 - Round Length (millimeters)



- **Simple Hole, Multistep Hole:**
 - Diameter (millimeters),
 - Length and Depth (millimeters)
 - Volume (mm³)
 - Surface Area (mm²)

- Maximum diameter and Minimum diameter (millimeters—for multistep holes)
- Step count (for multistep holes)
- Hole type (THROUGH or BLIND)
- Blind, Sleeve Pin, Threaded, Countersunk, and Flanged (TRUE or FALSE)
- Accessibility (THROUGH, OBSCURED, SIDE_A, SIDE_B, or UNDERCUT--determines operation sequence and tooling requirements.)

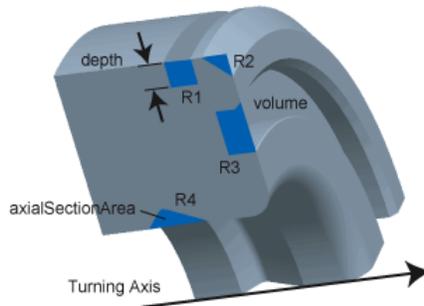
Simple Hole



■ Ring:

- Depth (millimeters)
- Min Wall Thickness (millimeters)
- Volume (mm³)
- Axial Section Area (millimeters)

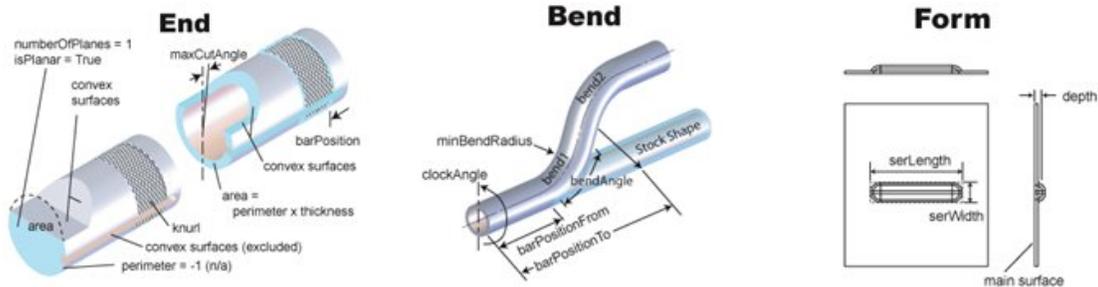
Ring



■ Bending/Forming (Bends, Ends, Forms):

- Area (mm²)
- Bar Position (millimeters)
- Max Cut Angle (degrees)
- Outer Perimeter (millimeters)
- Bend Angle (degrees)

- Min Bend Radius (millimeters)
- Neutral Bend Radius (millimeters)
- Is Circular (Boolean, Bends only)
- Is Planar (Boolean, Bends only)
- SER Length (millimeters)
- SER Width (millimeters)



See also [Extrusion GCDs](#).

Extrusion GCDs

If you have licensed the Extrusions cost model, aPriori attempts to recognize parts that can be manufactured from extruded stock with punching, bending, and/or light-to-moderate machining. In order to do this, aPriori determines the geometry of the workpiece in an unbent state, with holes and cutouts filled in. For the workpiece in that state, if there is a direction along which the cross-sections are all the same, the part is recognized as an extrusion.

Note: Extrusions are recognized by default in starting point VPEs. To disable extrusion recognition, set the site variable `enableGenericExtrusions` to **false**.

Note: For heavily machined, extruded parts, use 2-model machining.

Important GCDs for extrusions include the following:

- CrossSection GCD. Important properties include:
 - Shape: for extrusions, this is set to **GENERIC_EXTRUSION**.
 - Outside Diameter: diameter of the CrossSection's smallest enclosing circle
 - Max Thickness: maximum thickness of the part
 - Perimeter: perimeter of the CrossSection
- CrossSectionHollow GCD: region of a CrossSection such that one of the following holds:
 - Fully hollow CrossSectionHollow: region is bounded by an internal contour.
 - Semi-hollow CrossSectionHollow: region is not occupied by the part and is surrounded, except for a small gap, by part of the part's external contour. A

gap is considered small if the square of its length is less than two and half times the hollow area.

The cross sections shown below have fully hollow regions:



The cross sections shown below have semi-hollow regions:



Important properties include:

- Gap Length: length of the gap in the contour surrounding the hollow. This is 0 for fully hollow CrossSectionHollow GCDs.
- Area: area of the hollow.
- Symmetric: true if the hollow is symmetric with respect to a line extending from the gap midpoint.
- Cutout GCD: represents a volume of material that is removed either interior to the part or adjacent to an end of the part. For parts made from custom extrusion profiles, these are extracted instead of ComplexHole GCDs (which provide less information about accessibility and applicable tool sizes). Cutout GCDs may either be machined with a 3-Axis or 5-Axis CNC Router, or may be punched with a Tube Laser.

Feasibility and Routing

When you choose the **Bar&Tube Fab** process group, aPiori selects process-level routings, operation-level routings, as well as machines and materials. These procedures are described in the following sections:

- Process-level Routing
- Process-level Feasibility
- Material Selection
- Machine Selection
- Operation-level Feasibility and Routing

Process-level Routing

Process routings for **Bar&Tube Fab** are divided into the following categories and subcategories:

- **Bent Part** routings:
 - **CTL/[Punch]/[Bend]**: Performs cutting with a saw or shear, followed by optional punching, bending, trimming, and/or forming.
 - **Tube Laser/[Punch]/[Bend]**: Performs cutting and hole making with a tube laser, followed by optional punching, bending, trimming, and/or forming.
- **Unbent Part** routings:
 - **CTL/[Punch]**: Performs cutting with a saw or shear, followed by optional punching, trimming, and/or forming.

- **Tube Laser/[Punch]:** Performs cutting and hole making with a tube laser, followed by optional punching, trimming, and/or forming.
- **Roll Bending:** Performs cutting followed by rolling, followed by laser seam welding.

Following are the available routings for each subcategory (optional processes are in brackets):

- **CTL/[Punch]/[Bend]:** [Cut To Length] > [Punching] > [Bending] > [Punching] > [Trimming] > Forming
- **Tube Laser/[Punch]/[Bend]:** [Tube Laser] > [Punching] > [Bending] > [Punching] > [Trimming] > Forming
- **CTL/[Punch]:** [Cut To Length] > [Punching] > [Trimming] > Forming
- **Tube Laser/[Punch]:** [Tube Laser] > [Punching] > [Trimming] > Forming
- **Roll Bending:** Sheet Blank Cut > Rolling > Laser Seam Welding > [Punching] > [Tube Laser] > Forming

Note: Roll Bending is never auto-evaluated; you must manually select it.

Note that even though **Forming** is non-optional, all of its subprocesses are optional.

Every routing has a special initial process or group of processes:

- **Sheet Stock** for **Roll Bending** routings: serves as the locus of material cost and utilization calculations (see [Material Cost and Utilization](#)).
- **Material Stock Extrusion** for extrusions routings: consists of Billet Preheat, Die Preheat, and Extrusion. The Extrusion process serves, among other things, as the locus of material cost and utilization calculations (see [Extrusion](#)).
- **Material Stock** for all other routings: serves as the locus of material cost and utilization calculations (see [Material Cost and Utilization](#)).

Note that end forming is not supported for extrusions.

Cut to Length is one of the following alternative processes:

- **Band Saw**
- **Circular Saw**
- **Reciprocating Saw**
- **Plasma CNC**
- **Plasma Torch**
- **OxyFuel Torch**
- **Shear**

Circular Saw, **Reciprocating Saw**, **Plasma Torch**, **OxyFuel Torch**, and **Shear** are never auto-evaluated.

Bending is one of the following alternative processes:

- **Rotary Draw Bending**
- **Compression Bending**
- **Bar Bend Brake**

Trimming is one of the following alternative processes:

- **Band Saw**

- **Circular Saw**
- **Reciprocating Saw**
- **Shear**

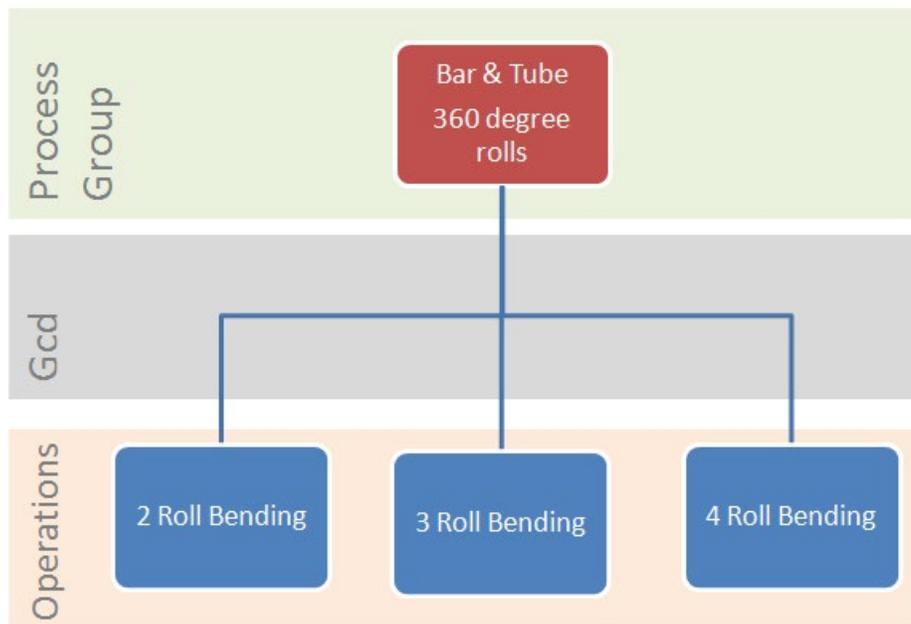
Circular Saw, Reciprocating Saw, and Shear are never auto-evaluated.

Sheet Blank Cut is one of the following alternative processes:

- **Sheet Laser Cut**
- **Sheet Plasma Cut**
- **Sheet OxyFuel Cut**

Rolling is one of the following alternative processes:

- **2 Roll Bending**
- **3 Roll Bending**
- **4 Roll Bending**



Forming is the following sequence of processes (each element of which is optional):

- **Reduction**
- **Expansion**
- **Flaring**
- **Flanging**
- **Flattening**
- **Bar Forming**
- **Slotting**
- **Notching**
- **Knurling**

Tube Laser and **Punching** have no subprocesses.

You can manually assign **Forming** processes to each end of a part. However, some stock shapes do not support all processes (see [Process-level Feasibility](#)).

Certain parts require you to manually specify additional processes for **Punching** or **Trimming**. For example, parts with bend features close to an end may require extra trim material for the bend machine to grip--the extra material is trimmed after the bending process. Similarly, some parts require a punching process after a bending process. You can add these additional processes by using the **Routing Selection** dialog.

For routings with two occurrences of **Punching**, you must manually specify which holes are handled by the second punching process by moving them from the first punching process to the second one. Follow these steps to move a hole:

- 1 In the **Manufacturing Process** panel, expand the current punching process and operations to view the list of holes associated with it.
- 2 Left click the desired hole and drag it to the second punching process. The hole appears under the new process.

If you have licensed the Machining process group, your routing can include any of the following secondary processes:

- 3-Axis Milling
- Cylindrical Grinding
- Gun Drill
- 2-axis Wire EDM operations
- Single Index Milling and Rotor Grinding operations (if helical groove geometry is present)

If you have licensed the optional Turning module, your routing can include the turning processes using the following lathe types:

- 2-axis
- 3-axis
- 4-axis
- 6-axis

Your routing can also include the following subsequent optional processes, if you have licensed these modules:

- Heat Treatment
- Surface Treatment
- Part Assembly
- Other Secondary Processes (packaging)

Process-level Feasibility

The following table lists the feasible stock forms for each process:

											
	Square Tub	Square Bar	Round Tub	Round Bar	Rect Tube	Rect Bar	Angle Bar	Channel Bar	Hex Bar	I-Beam	T-Beam
3-Roller Bending			X								
Band Saw	X	X	X	X	X	X	X	X	X	X	X
Bar Bend Brake		X		X		X			X		
Bar Forming	X	X	X	X	X	X			X		
Circular Saw	X	X	X	X	X	X	X	X	X	X	X
Compression Bending	X	X	X	X	X	X			X		
Expansion			X								
Flanging			X								
Flaring			X								
Flattening	X	X	X	X	X	X			X		
Knurling			X	X							
Notching	X		X		X		X				
OxyFuel Torch										X	X
Plasma CNC										X	X
Plasma Torch										X	X
Punching	X	X	X	X	X	X	X		X		
Reciprocating Saw	X	X	X	X	X	X	X	X	X	X	X
Reduction			X								
Rotary Draw Bending	X	X	X	X	X	X	X		X		
Shear	X	X		X		X	X		X		
Sheet Laser			X								
Sheet OxyFuel			X					X			
Sheet Plasma			X								
Slotting	X		X		X						
Tube Laser	X		X		X		X			X	X

The following processes have additional feasibility requirements:

- **Bar Bend Brake**
 - Each bend is circular (the curve of the bend is a portion of a circle), that is, no bend has the value false for the GCD property **Is Circular**.
- **Compression Bending**
 - Each bend is either planar (lies in a single plane) or circular (the curve of the bend is a portion of a circle), that is, no bend has the value false for both **Is Planar** or **Is Circular**.
- **Tube Laser**
 - Holes are not flanged, countersunk, or threaded.
- **Sheet Laser Cut, Sheet Oxy Fuel Cut, Sheet Plasma Cut**
 - Part has no flanged holes, countersunk holes, threaded holes, or forms.
- **Rolling**
 - Diameter to Thickness ratio exceeds the minimum ratio.
 - Part does not have expansions, reductions, or bends.
 - Part bend is a full 360°.

For the following processes, if tolerance or roughness are not within Process Tolerance Capability, aPiori adds a machining process to the routing:

- **Tube Laser**
- **Punching**
- **Laser Cut, Oxy Fuel Cut, Plasma Cut**

Note that in some cases this can result in inflated costs, because when machining is required to obtain the required tolerance, the actual manufacturing process will use machining to create the hole, rather than using one of the above processes followed by machining.

See also [Extrusion Routing Feasibility](#).

Extrusion Routing Feasibility

The Extrusion process is feasible only if all the following hold:

- Material type: Current material's **Material Type** is **Aluminum**.
- Critical tongue ratio: If the part has at least one semi-hollow **CrossSectionHollow** (see [Extrusion GCDs](#)), the part's **Critical Tongue Ratio** must be no greater than the value of the cost model variable **defaultMaximumTongueRatio** (14 in starting point VPEs).
- Material exit speed limits: Values for the material properties **Minimum Extrusion Exit Speed** and **Maximum Extrusion Exit Speed** must be present for the current material in the material table.

The Billet Preheat and Die Preheat processes are feasible only if values are present in the material table for the properties **Specific Heat RT** and **Solidus Temp**.

Material Selection

In direct integration mode with Pro/ENGINEER, if the composition selection mode is **MCAD**, aPriori selects the MCAD composition from the part, if available. Otherwise aPriori selects the VPE default material (Steel, HR, AISI 1010 for all starting point VPEs).

In CAD-independent mode, aPriori selects the VPE default material (Steel, HR, AISI 1010 for all starting point VPEs).

In both direct integration and CAD-independent mode, you can use aPriori's selection or else manually select a material composition and override the material unit cost. To manually specify a material, select **Edit > Material Selection** in the Manufacturing Process pane (see also [Selecting material in Manufacturing Process Information](#)).

You can select from a list of common stock sizes or from virtual stock. Actual stock can be automatically or manually selected. Actual stock uses the stock's unit cost. Virtual stock uses the material composition's unit cost and assumes a virtual sheet length of 20 ft.

For extrusions, the material must be aluminum—see [Extrusion Routing Feasibility](#).

You can override the unit cost if desired. aPriori chooses to use actual or virtual stock based on the cross section recognition and size. You can override the part cross section. In addition, you can specify the use of a custom cut for which you can choose to use a **Size to Fit Trim** or a **Custom Size Length**, both specified in millimeters.

Machine Selection

If aPriori is configured to automatically select a machine, it generally selects the machine with the lowest overhead rate that satisfies all the feasibility rules. (Note that aPriori never auto-selects **Roll Bending** in the Bar & Tube process group. You must manually select it.)

For end cutting operations, the machine selection affects the cut speed and axial feed speed used to create the ends. The cut speed can vary across processes and machines. In general, a more powerful machine has a faster cut speed. Cut speed also varies based on material composition and thickness.

For forming operations, the machine selection affects the bend/form time, bend traversal time, and stock rotation time. Similarly, for hole-making operations, the machine selection affects the cutting time and hole traversal time.

For Extrusion, aPiori selects the feasible machine that results in the lowest cost per mass (see [Machine Selection for Extrusion](#)).

Following are the machine feasibility requirements:

- **Band Saw, Circular Saw, Reciprocating Saw**
 - Stock fits within the machine's Max Stock Height and Max Stock Width.
 - End cuts are planar.
 - Ends max cut angle does not exceed the machine's Max Cut Angle.
- **Tube Laser**
 - Stock diameter does not exceed the machine's Max Stock Diameter.
 - Stock length does not exceed the machine's Max Stock Length.
 - Stock thickness does not exceed the machine's Max Stock Thickness.
- **Punching**
 - Stock fits within the machine's Max Stock Diameter, Length, and Thickness.
 - Required punch force (based on max hole perimeter, wall thickness, material Shear Strength, and machine Punch Tip Factor) does not exceed the machine's Punch Force.
 - Stock form is compatible according to the machine property Stock Compatibility.
 - Hole diameter to wall thickness ratio exceeds the machine's Min Hole Dia-to-Thickness Ratio
 - Hole diameter does not exceed the machine's Max Hole Diameter.
- **Bar Bend Brake**
 - Material thickness does not exceed the machine's Max Thickness.
 - Part's largest bend radius to thickness ratio does not exceed the machine's Max Radius-to-Thickness Ratio.
 - Part's smallest bend radius to thickness ratio exceeds the machine's Min Radius-to-Thickness Ratio.
- **Compression Bending**
 - Tube diameter falls within the machine's Max Tube Diameter and Min Tube Diameter.
 - Part's center-line radius falls within the machine's Max Part Center-Line-Radius and Min Part CenterLine-Radius.
 - Distance between bends exceeds the machine's Min Distance Between Bends.
 - Bend angle does not exceed the machine's Max Bend Angle.
- **Rotary Draw Bending**

-
- Tube diameter falls within the machine's Max Tube Diameter and Min Tube Diameter.
 - Part's center-line radius falls within the machine's Max Part Center-Line-Radius and Min Part CenterLine-Radius.
 - Distance between bends exceeds the machine's Min Distance Between Bends.
 - Bend angle does not exceed the machine's Max Bend Angle.
 - **Bar Forming, Expansion, Flanging, Flaring, Flattening, Knurling, Notching, Reduction, Slotting**
 - Stock diameter falls within the machine's Max Stock Diameter and Min Stock Diameter.
 - **Laser Cut, Oxy Fuel Cut, Plasma Cut**
 - Blank fits on the machine according to the machine's Bed Length and Bed Width.
 - Material thickness does not exceed the machine's Max Thickness.
 - **Shear**
 - Material thickness does not exceed the machine's Max Thickness.
 - Part height does not exceed the machine's maximum height for the current stock shape.
 - Part outside diameter does not exceed the machine's Max Diameter.
 - Part cut width does not exceed the machine's maximum width for the current stock shape.
 - **2 Roll Bending**
 - Part inside diameter is greater than machine minimum diameter (1.15X top roll diameter)
 - Part length is less than machine roll working Length
 - Part thickness is less than machine maximum thickness (factor of material yield strength and maximum machine working length /part length)
 - **3- and 4-Roll Bending**
 - Part inside diameter is greater than machine single pass diameter (~ 1.3 to 3X top roll diameter)
 - Part length is less than machine roll working length
 - Part thickness is less than machine maximum thickness (factor of material yield strength and maximum machine working length /part length))
 - Part weight is less than machine maximum part weight
 - **Extrusion**
 - A single part can fit within the usable area of the die face.
 - Some acceptable ram speed (based on part complexity, number of die cavities, and quench type) must result in an exit speed that is within range for the current material.
 - Maximum acceptable ram speed (see above) must exceed the global lower bound on ram speed specified by the cost model variable **minimumAcceptableRamSpeed**.
 - Machine's maximum billet volume can accommodate at least one part.

- If the user has used a setup option to specify **Billet Length**, then it must fall between the machine's maximum and minimum billet length.
- Part length must be less than the machine's runout length.

See **Machine Selection for Extrusion** for more information.

Note: For Roll Bending, machine maximum thickness is typically the maximum pre-bend thickness. Machine capacities are usually rated for steel A36 with a tensile yield strength of 36000 psi. This is the reference material strength. To find the maximum thickness for other materials we use the following equation:

$$Max\ Thickness_{material\ x} = Maxthickness_{reference\ material} * \sqrt{\frac{Yield\ Strength\ of\ reference\ material}{yield\ strength\ of\ material\ x}}$$

The pre-bend thickness given in machine specs are usually given for the maximum plate width. If the part length is less than the maximum plate length, the pre-bend thickness usually increases. So a ratio of machine maximum working length/part length is applied in the maximum thickness calculation.

$$Max\ Thickness_{material\ x} = Maxthickness_{reference\ material} * \sqrt{\frac{Yield\ Strength\ of\ reference\ material}{yield\ strength\ of\ material\ x}} * \frac{MaxMachinePlateWidth}{part\ length}$$

Machine Selection for Extrusion

For Extrusion, aPiori selects the feasible machine that results in the lowest cost per mass extruded. Cost per mass extruded is calculated as follows:

Cost per Mass = Machine Direct Overhead Rate / Machine Mass Rate

Cost per mass depends on the following:

- Machine direct overhead rate: specified by the machine property **Direct Overhead Rate**.
- Machine mass rate: see formula.

Machine Mass Rate =

Total Extrudate Cross Section Area * Exit Speed * Material Density

Machine mass rate depends on the following:

- Total extrudate cross-sectional area: this is the product of the **Number of Die Cavities** and the value of the geometric property **Area** for the CrossSection GCD.
- Exit speed: see **Maximum Acceptable Ram Speed**.
- Material Density: specified by the material property **Density**. This value is converted from kg/m³ to kg/mm³ for use in this formula.

An Extrusion machine is feasible only if all the following hold:

- A single part can fit within the usable area of the die face. This means the radius of the part cross section is less than the radius of the die face minus a clearance allowance. These radii and clearance values are determined as follows:
 - Radius of the cross section is the radius of the cross section's smallest enclosing circle, given by half the geometric property **Outside Diameter** for the CrossSection GCD.

-
- Radius of the die face is given by half the product of the machine property **Billet Diameter**. And the tool shop variable **Die Diameter Adjustment Factor**.
 - Clearance allowance is looked up in the lookup table **tblStandardSizes**. It is given by the value in the Size column for the row that has **dieClearanceForNesting** in the Variable column and the current system units (**US** or **metric**) in the Unit column.
 - Some acceptable ram speed must result in an exit speed that is within range. What counts as an in-range exit speed is specified by the following:
 - Material property **Minimum Extrusion Exit Speed**
 - Material property **Maximum Extrusion Exit Speed**
 What counts as an acceptable ram speed depends on the following:
 - **Part Complexity Reduction Factor**
 - **Quench Type**
 - **Number of Die Cavities**

See also **Maximum Acceptable Ram Speed**.

Acceptable ram speed is bounded above by the machine property **Max Ram Speed**.

- The maximum acceptable ram speed must exceed the global lower bound on ram speed, specified by the cost model variable **minimumAcceptableRamSpeed** (1mm/sec in starting point VPEs).
- Machine's maximum billet volume can accommodate at least one part (see **Billet Size and Parts per Billet**).
- Part **Length** is less than the Machine property **Max Runout Length**.
- If the user has used a setup option to specify **Billet Length**, then it must fall between the machine's maximum and minimum billet length, specified by the machine properties **Max Billet Length** and **Min Billet Length**.

Operation-level Feasibility and Routing

Below are the bar and tube operations that have associated feasibility rules, grouped by GCD type. Each operation is accompanied by necessary conditions for the operation's selection. aPriori checks the operations in the order specified by the operation templates, and selects the first operation for which the current GCD satisfies all the necessary conditions.

Bend

- *Compression Bending*
 - Distance between this bend and all other bends is greater than or equal to the machine property **Minimum Distance Between Bends**.
 - Bend angle is less than or equal to the machine property **Maximum Bend Angle**.
- *Rotary Draw Bending*
 - Distance between this bend and all other bends is greater than or equal to the machine property **Minimum Distance Between Bends**.
 - Bend angle is less than or equal to the machine property **Maximum Bend Angle**.

Complex Hole

- *ComplexHoleLaserCutting*

-
- Tube thickness is nonzero.
 - Tolerance is nonzero.
 - GCD is not flanged.
 - Tolerance is greater than or equal to the minimum allowable tolerance given the GCD's MEC (maximum enclosed circle) diameter and the current machine. This minimum tolerance is the product of the following values: (1) value for the GCD's MEC diameter in the lookup table **toleranceCapability**, (2) the machine property **toleranceFactor**, and, if the GCD's length is greater than the plant variable **thinToThickCutThreshold**, (3) the plant variable **thickCutToleranceFactor**.
 - **ComplexHolePunching**
 - MEC (maximum enclosed circle) diameter is nonzero. (The MEC diameter is the diameter of the largest circle that fits in the complex hole.)
 - Length (depth) is nonzero.
 - Tolerance is nonzero.
 - MEC diameter-to-thickness ratio is greater than or equal to the machine property **minHoleDTratio**.
 - MEC diameter is less than or equal to the machine property **maxHoleDia**.
 - Tolerance is greater than or equal to the minimum allowable tolerance given the GCD's MEC diameter and the current machine. This minimum tolerance is the product of the following values: (1) value for the GCD's MEC diameter in the lookup table **toleranceCapability** and (2) the machine property **toleranceFactor**.

Curved Surface

- **AsSupplied**
 - Part length equals stock length.
 - GCD is planar.
- **Bar & Tube Fab**
 - Roughness is greater than or equal to site default roughness (**roughnessDefault**).
 - Tolerance is greater than or equal to site default tolerance (**toleranceDefault**).
- **CurvedSurfaceAsSuppliedSurface**
 - GCD is a stock surface or part of a complex hole or a non-ring surface in tube stock
- **EndSawingSurface**
 - GCD is accessible to a saw.

Curved Wall

- **AsSupplied**
 - Part length equals stock length.
 - GCD is planar.
- **Bar & Tube Fab**
 - Roughness is greater than or equal to site default roughness (**roughnessDefault**).
 - Tolerance is greater than or equal to site default tolerance (**toleranceDefault**).

-
- *CurvedWallAsSuppliedSurface*
 - GCD is a stock surface or part of a complex hole or a non-ring surface in tube stock
 - GCD is not threaded.
 - *EndSawingSurface*
 - GCD is accessible to a saw.

End

- *AsSupplied*
 - Part length equals stock length.
 - GCD is planar.
- *Shearing*
 - GCD has at least one planar child GCD.

Form

- *Expansion*
 - GCD is an expansion.
 - GCD is adjacent to an end.
- *FormAsSupplied*
 - GCD is a supported type of form.
 - GCD is either adjacent to an edge or neither reduction nor expansion.
- *Reduction*
 - GCD is a reduction.
 - GCD is adjacent to an end.

Multistep Hole

- *MultiStepHoleLaserCutting*
 - Inner-hole diameter is nonzero.
 - Inner-hole length (depth) is nonzero.
 - Inner-hole tolerance is nonzero.
 - Inner hole is not flanged.
 - Inner hole is not threaded.
 - Inner hole is not countersunk.
 - Inner hole is not blind.
 - Roughness is greater than or equal to site default tolerance (**roughnessDefault**).
 - Tolerance is greater than or equal to the minimum allowable tolerance given the inner-hole diameter and the current machine. This minimum tolerance is the product of the following values: (1) value for the inner-hole diameter in the lookup table **toleranceCapability**, (2) the machine property **toleranceFactor**, and, if the GCD's length is greater than the plant variable **thinToThickCutThreshold**, (3) the plant variable **thickCutToleranceFactor**..
- *MultiStepHolePunching*
 - Inner-hole diameter is nonzero.
 - Inner-hole length (depth) is nonzero.
 - Inner-hole tolerance is nonzero.

-
- Inner-hole diameter-to-thickness ratio is greater than or equal to the machine property **minHoleDTratio**.
 - Inner-hole diameter is less than or equal to the machine property **maxHoleDia**.
 - Inner hole is not threaded.
 - Inner hole is not countersunk.
 - Inner hole is not blind.
 - Roughness is greater than or equal to site default tolerance (**roughnessDefault**).
 - Tolerance is greater than or equal to the minimum allowable tolerance given the inner-hole diameter and the current machine. This minimum tolerance is the product of the following values: (1) value for the inner-hole diameter in the lookup table **toleranceCapability** and (2) the machine property **toleranceFactor**.

Planar Face

- *AsSupplied*
 - Part length equals stock length.
 - GCD is planar.
- *Bar & Tube Fab*
 - Roughness is greater than or equal to site default roughness (**roughnessDefault**).
 - Tolerance is greater than or equal to site default tolerance (**toleranceDefault**).
- *EndSawingSurface* (cutting and trimming)
 - GCD is accessible to a saw.
- *PlanarFaceAsSuppliedSurface*
 - GCD is a stock surface or part of a complex hole or a non-ring surface in tube stock

Ring

- *RingAsSupplied*
 - This operation is never feasible (unless infeasibility is manually overridden).

Simple Hole

- *LaserOnly*
 - Diameter is nonzero.
 - Length (depth) is nonzero.
 - Tolerance is nonzero.
 - GCD is not flanged.
 - GCD is not threaded.
 - GCD is not countersunk.
 - GCD is not blind.
 - Roughness is greater than or equal to site default tolerance (**roughnessDefault**).
 - Tolerance is greater than or equal to the minimum allowable tolerance given the GCD's dimensions and the current machine. This minimum tolerance is the product of the following values: (1) value for the GCD's diameter in the lookup table **toleranceCapability**, (2) the machine property **toleranceFactor** , and,

if the GCD's length is greater than the plant variable **thinToThickCutThreshold**, (3) the plant variable **thickCutToleranceFactor**.

- **PunchOnly**
 - Diameter is nonzero.
 - Length (depth) is nonzero.
 - Tolerance is nonzero.
 - Diameter-to-thickness ratio is greater than or equal the machine property **minHoleDTratio**.
 - Diameter is less than or equal to the machine property **maxHoleDia**.
 - GCD is not threaded.
 - GCD is not countersunk.
 - GCD is not blind.
 - Roughness is greater than or equal to site default tolerance (**roughnessDefault**).
 - Tolerance is greater than or equal to the minimum allowable tolerance given the GCD's diameter and the current machine. This minimum tolerance is the product of the following values: (1) value for the GCD's diameter in the lookup table **toleranceCapability** and (2) the property **toleranceFactor**.
- **SimpleHoleAsSupplied**
 - GCD is the interior of a tube (the part is made from tube stock, the GCD's center is on a turning axis, and the GCD's diameter equals the part's cross-section diameter).
- **SimpleHoleLaserCutting**
 - Diameter is nonzero.
 - Length (depth) is nonzero.
 - Tolerance is nonzero.
 - GCD is not threaded.
 - GCD is not countersunk.
 - GCD is not blind.
- **SimpleHolePunching**
 - Diameter is nonzero.
 - Length (depth) is nonzero.
 - Tolerance is nonzero.
 - Diameter-to-thickness ratio is greater than or equal the machine property **minHoleDTratio**.
 - Diameter is less than or equal to the machine property **maxHoleDia**.
 - GCD is not threaded.
 - GCD is not countersunk.
 - GCD is not blind.

Cost Algorithms and Calculations

If machining processes are included as secondary processes on bar and tube components, then the machining costs are computed via the **Machining** cost model and

combined with the **Bar&Tube** process costs to produce a total manufacturing process cost.

This section details how costs are calculated by aPriori. Note that you can override the calculation of many of the quantities involved, and specify them explicitly—see [User Inputs](#), below.

When not otherwise specified, costs are per part.

Note that Extrusion formulas are covered in [Extrusion](#).

This section covers formulas in the following areas:

- Yields for Bar & Tube Fabrication
- Material Cost and Utilization
- Batch Setup
- Band Saw, Circular Saw, Reciprocating Saw
- Tube Laser
- Punching
- Bar Bend Brake
- Compression Bending
- Rotary Draw Bending
- Forming
- Laser Cut, Oxy Fuel Cut, Plasma Cut
- Shear
- 3-Roller Bending
- Roll Bending (2-, 3-, and 4-roll)
- Extrusion
- Billet Preheat
- Die Preheat

Yields for Bar & Tube Fabrication

Yields are calculated with the following formulas:

Final Yield = Final Output Volume / Local Input Volume

Final yield affects material, labor, and overhead costs per part. It is the fraction of parts created by this process in the current production scenario that will survive as good parts once any secondary processes are completed. That is, final yield is the fraction of parts created by this process that are *not* discarded as scrap parts, either by this process or by a downstream process. Final yield depends on the following:

- Final output volume is the number of parts created by this process that are *not* discarded as scrap parts, either by this process or by a downstream process. It is the product of the annual volume and number of production years, specified in the Production Scenario screen of the Cost Guide.

-
- Local Input volume (see the formula below). This is the total number of parts produced by this process, including all parts discarded as scrap from this process or downstream processes.

Local Input Volume = Local Output Volume + Number of Scrap Parts for This Process

Local input volume is the total number of parts produced by this process in the current scenario, including all parts discarded as scrap from this process or downstream processes. It is the sum of the following:

- Local output volume (see the formula below). This is the number of parts produced by this process, excluding parts discarded as scrap by this process, but including parts that are discarded as scrap by downstream processes.
- Number of scrap parts for this process (see the formula below)

Local Output Volume = Final Output Volume + Number of Scrap Parts Downstream

Local output volume is the number of parts produced by this process in the current scenario, excluding parts discarded as scrap by this process, but including parts that are discarded as scrap by downstream processes. It is the sum of the following:

- Final output volume is the number of parts created by this process that are *not* discarded as scrap parts, either by this process or by a downstream process. It is the product of the annual volume and number of production years, specified in the Production Scenario screen of the Cost Guide
- Number of Scrap Parts Downstream. This the number of parts discarded as scrap by downstream processes.

Number of Scrap Parts for This Process = (Local Output Volume / Local Good Part Yield) – Local Output Volume

Number of scrap parts for this process is the number of parts produced by this process in the current scenario that are discarded as scrap by this process, before any downstream process is performed on them. It is a function of the following:

- Local output volume (see the formula above). This is the number of parts produced by this process, excluding parts discarded as scrap by this process, but including parts that are discarded as scrap by downstream processes.
- Local good part yield (specified by the machine property **Good Part Yield**). This is the fraction of parts produced by this process that are not discarded as scrap by this process but may be discarded as scrap by downstream processes.

Material Cost and Utilization

aPriori provides three options for calculating utilization, which the user can choose from in the **Material Selection** dialog.

- **Computed** (see below)
- **Machine Default** (determined by the machine property **Avg Utilization**)
- **Override** (fixed percent value entered by user)

aPriori assumes the part is nested along the length of a stock piece. The rough mass is equal to the total mass of the stock divided by the number of parts nested on the stock. In some cases where the part may require a secondary trim operation after forming (for example, if a bend is very close to one end), nesting will automatically account for this required trim.

The current nesting pattern on the currently selected stock is viewable in the Viewer using the **Analysis** menu. The stock can be changed via the **Material Selection** dialog.

Material Cost = Raw Material Cost – Scrap Material Credit – Scrap Part Credit

Material Cost depends on the following:

- Raw material cost: see formula
- Scrap material credit: see formula.
- Scrap part credit: see formula.

Raw Material Cost = (Material Cost Per Mass * Rough Mass) / Final Yield

Raw material cost is the cost of material for one part, including the cost of scrap produced during manufacture of the part, as well as the amortized cost of scrapped parts. It depends on the following:

- Material cost per mass: specified by the material property **Cost per KG**.
- Rough mass: see formula.
- Final yield: see [Yields for Bar & Tube Fabrication](#).

Rough Mass = Finish Mass / Utilization

Rough mass depends on the following:

- Finish mass: product of part **Volume** and material **Density**.
- Utilization: see formula.

Utilization = (Number of Parts Per Stock * Finish Mass) / Stock Mass

Utilization depends on the following:

- Number of parts per stock: based on linear nesting and trim allowance (if needed).
- Finish mass: product of part **Volume** and material **Density**.
- Stock Mass: product of stock length, part cross-sectional area, and material density.

Scrap Material Credit = Material Cost Per Mass * Scrap Cost Percent * Scrap Mass

Scrap material credit is the product of the following:

- Material cost per mass: specified by the material property **Cost per KG**.
- Scrap cost percent: this is 0 if the setup option [Enable Scrap Material Credit](#) is un-checked (the default in starting point VPEs). Otherwise, it is specified as a percentage by the material property **Scrap Cost Percent**.
- Scrap mass: see formula.

Scrap Mass = Rough Mass – Finish Mass

Scrap mass depends on the following:

- Rough mass: see formula.
- Finish mass: product of part **Volume** and material **Density**.

$$\text{Scrap Part Credit} = \frac{(\text{Material Cost per Kg} * \text{Scrap Cost Fraction}) * ((\text{Number of Scrap Parts} + \text{Number of Scrap Parts Down Stream}) * \text{Rough Mass})}{\text{Total Production Volume}}$$

Scrap part credit is 0 if the setup option [Enable Scrap Part Credit](#) is set to **false**. Otherwise, it is the product of the following:

- Material cost per mass: specified by the material property **Cost per KG**.
- Scrap cost fraction: this is 0 if the setup option is un-checked (the default in starting point VPEs). Otherwise, it is specified as a percentage by the material property **Scrap Cost Percent**.
- Number of scrap parts: number of parts discarded as scrap by this process. See [Yields for Bar & Tube Fabrication](#).
- Number of scrap parts down stream: number of parts discarded as scrap by downstream processes. See [Yields for Bar & Tube Fabrication](#).
- Rough mass: see formula
- Total production volume: specified in the Production Scenario tab of the Cost Guide.

Batch Setup

$$\text{Amortized Batch Setup} = \frac{(\text{Machine Setup Time} * (\text{Machine Labor Rate} + \text{Direct Overhead Rate}))}{\text{Batch Size}}$$

Amortized batch setup is a function of the following:

- Machine setup time (specified as a machine property)
- Machine labor rate (specified as a machine property)
- Direct overhead rate (see [Direct and Indirect Overhead](#))
- Batch size (specified in the **Production Info** dialog)

Band Saw, Circular Saw, Reciprocating Saw

aPriori uses the formulas below to determine costs associated with sawing processes (used for cutting and trimming).

Accounting Calculations

$$\text{Labor Time} = \text{Cycle Time} * \text{Machine Labor Time Standard} * \text{Machine Labor Ratio}$$

Labor time is the product of the following

- Cycle time (see [Cycle Time Calculation](#))
- Machine labor time standard (specified as a machine property). This value reflects the amount of time spent by machine operators in between machine cycles, including time performing maintenance and cleaning tasks as well as time pausing between tasks. The amount is expressed as a cycle time multiplier.
- Machine labor ratio (specified as a machine property)

$$\text{Labor Cost} = ((\text{Labor Time} / 3600) * \text{Machine Labor Rate}) / \text{Final Yield}$$

Labor cost is a function of the following:

- Labor time (see formula above)
- Machine labor rate (specified by a machine property)
- Final yield

$$\text{Amortized Batch Setup} = (\text{Machine Setup Time} * (\text{Machine Labor Rate} + \text{Direct Overhead Rate})) / \text{Batch Size}$$

Amortized batch setup is a function of the following:

- Machine setup time (specified as a machine property)
- Machine labor rate (specified as a machine property)
- Direct overhead rate (see [Direct and Indirect Overhead](#))

Cycle Time Calculation

$$\text{Cycle Time} = \text{Sawing Time} + \text{Handling Time}$$

Cycle time is the sum of the following:

- Sawing time (see formula below)
- Handling time (see formula below)

$$\text{Sawing Time} = \text{First End Cut Time} + \text{Other End Cut Times} + \text{Feed Forward Time}$$

Sawing time is the sum of the following:

- End cut times, which increase as the following quantities increase:
 - End surface area
 - Number of planes on ends

Cut times also depend on material type (aluminum, for example, cuts faster than steel).

Cut times are obtained from lookup in one of the following lookup tables, where lookups are keyed by material type and stock width:

- **bandSawCutting**
- **circularSawCutting**
- **resiprocatingSawCutting**
- Feed forward time, which increases with the following:
 - Part's min stock length

Feed forward time decreases with the following:

- Machine's axial feed rate

$$\text{Handling Time} = (\text{Load Time} / \text{Number Parts Per Stock}) + (\text{Unload Time} / \text{Bundle Sawing Count}) + \text{Machine Unload Time}$$

Handling time depends on the following:

- Load time, which increases with the following:
 - Minimum stock length

-
- Part mass (which increases with material density)

Load and unload times are obtained from one of the following lookup tables, where lookup is keyed by stock mass (for load time) or bundle mass (for unload time):

- **bandSawHandling**
- **circularSawHandling**
- **resiprocatingSawHandling**
- Number parts per stock
- Unload time, which increases with part mass (and so with material density).

Load and unload times are obtained from one of the following lookup tables, where lookup is keyed by stock mass (for load time) or bundle mass (for unload time):

- **bandSawHandling**
- **circularSawHandling**
- **resiprocatingSawHandling**
- Bundle sawing count, which
 - Is 1 if angled cuts are present on ends
 - Decreases with stock width and height
 - Increases with machine's max stock width and height

Bundle sawing refers to the process of loading multiple bars or tubes onto the saw machine to cut multiple stock pieces at once, which in turn reduces cycle time. There is currently a bundle limit of 18 that applies to all processes and all machines. Enable this setting through Process Setup Options for Sawing processes.

- Machine unload time: for extrusions, this is 0. Otherwise, it is specified by the machine property **Unload Time**.

Tube Laser

aPiori uses the formulas below to determine costs associated with tube laser processes.

Accounting Calculations

Labor Time = Cycle Time * Machine Labor Time Standard * Machine Labor Ratio

Labor time is the product of the following

- Cycle time (see [Cycle Time Calculation](#))
- Machine labor time standard (specified as a machine property). This value reflects the amount of time spent by machine operators in between machine cycles, including time performing maintenance and cleaning tasks as well as time pausing between tasks. The amount is expressed as a cycle time multiplier.
- Machine labor ratio (specified as a machine property)

Labor Cost = ((Labor Time / 3600) * Machine Labor Rate) / Process Yield

Labor cost is a function of the following:

- Labor time (see formula above)

-
- Machine labor rate (specified by a machine property)
 - Process yield (see formula below)

Amortized Batch Setup = (Machine Setup Time * (Machine Labor Rate + Direct Overhead Rate)) / Batch Size

Amortized batch setup is a function of the following:

- Machine setup time (specified as a machine property)
- Machine labor rate (specified as a machine property)
- Direct overhead rate (see [Direct and Indirect Overhead](#))

Process Yield = 1 / (Machine Process Yield/100)

Process yield depend on the machine property **Process Yield**.

Programming Cost = Programming Time * (Machine Labor Rate + Direct Overhead Rate)

Programming cost depends on the following:

- Programming time (see formula below)
- Machine labor rate
- Direct overhead rate (see [Direct and Indirect Overhead](#))

Programming Time = Machine Base Programming Time + (Machine Programming Factor * Number of Programmed Features)

Programming time depends on the following:

- Machine base programming time
- Machine programming factor
- Number of programmed features (number of holes and ends to be handled by this process)

Cycle Time Calculation

Cycle Time = Burn Time + Pierce Time + Rapid Traverse Time + Handling Time

Cycle time is the sum of the following:

- Burn time (depends on cross-section thickness, material type, machine wattage, feature perimeters and radii of curvature)
- Pierce time (depends on number of holes, cross-section thickness, material type, machine wattage)
- Rapid traverse time (depends on machine's tube axial bar feed rate)
- Handling time (see formula below)

Pierce time per hole and burn cutting rate are derived from the lookup table **tubeLaserCutting**. Lookups are keyed by cross-section thickness, material type, and machine wattage. The table provides two burn cutting rates: one for large features and one for small features. A hole is considered small if its radius of curvature is less than or equal to the larger of the following:

- Machine property **smallFeatureFeedRadius**
- Product of part thickness and machine property **smallFeatureThicknessRatio**

Handling Time = (Load Time / Number Parts Per Stock) + Unload Time

Handling time depends on the following:

- Load time, which depends on min stock length and part mass (which depends on material density)
- Number of parts per stock
- Unload time, which depends on part mass (which depends on material density)

Load and unload times are determined with the help of the lookup table **tubeLaserHandling**. Load time lookup is keyed by stock mass. Unload time lookup is keyed by finish mass.

Punching

aPiori uses the formulas below to determine costs associated with punching processes (used for hole making).

Accounting Calculations

Labor Time = Cycle Time * Machine Labor Time Standard * Machine Labor Ratio

Labor time is the product of the following

- Cycle time (see [Cycle Time Calculation](#))
- Machine labor time standard (specified as a machine property). This value reflects the amount of time spent by machine operators in between machine cycles, including time performing maintenance and cleaning tasks as well as time pausing between tasks. The amount is expressed as a cycle time multiplier.
- Machine labor ratio (specified as a machine property)

Labor Cost = ((Labor Time / 3600) * Machine Labor Rate) / Process Yield

Labor cost is a function of the following:

- Labor time (see formula above)
- Machine labor rate (specified by a machine property)
- Process yield (see formula below)

Amortized Batch Setup =

$$\text{(Machine Setup Time * (Machine Labor Rate + Direct Overhead Rate)) / Batch Size}$$

Amortized batch setup is a function of the following:

- Machine setup time (specified as a machine property)
- Machine labor rate (specified as a machine property)
- Direct overhead rate (see [Direct and Indirect Overhead](#))

Process Yield = 1 / (Machine Process Yield/100)

Process yield depend on the machine property **Process Yield**.

Cycle Time Calculation

Cycle Time = (Total Punching Time / Number Punching Heads) + Load and Unload Time

Cycle time depends on the following:

-
- Total punching time (see formula below)
 - Number of punching heads (specified as the machine property **Number of Heads**)
 - Load and unload time (obtained from a lookup table—see below; increases with part mass, which increases with material density)

Total Punching Time = Punch Time + Traverse Time

Total punching time is the sum of the following:

- Punch time, which depends on whether holes are coaxial, as well as the following machine properties:
 - **Mandrel Punch Time**, or **Non Mandrel Punch Time**
 - **Axial Feed Rate**
- Traverse time, which depends on the following:
 - Distance between holes
 - Machine property **Axial Feed Rate**

Load and unload times by part mass are contained in the lookup table **punchHandling**.

See [User Inputs](#) for information on mandrel bending.

Bar Bend Brake

aPiori uses the formulas below to determine costs associated with this bending process.

Accounting Calculations

Labor Time = Cycle Time * Machine Labor Time Standard * Machine Labor Ratio

Labor time is the product of the following

- Cycle time (see [Cycle Time Calculation](#))
- Machine labor time standard (specified as a machine property). This value reflects the amount of time spent by machine operators in between machine cycles, including time performing maintenance and cleaning tasks as well as time pausing between tasks. The amount is expressed as a cycle time multiplier.
- Machine labor ratio (specified as a machine property)

Labor Cost = ((Labor Time / 3600) * Machine Labor Rate) / Process Yield

Labor cost is a function of the following:

- Labor time (see formula above)
- Machine labor rate (specified as a machine property)
- Process yield (see formula below)

Amortized Batch Setup =

$$\text{Amortized Batch Setup} = \frac{\text{Machine Setup Time} * (\text{Machine Labor Rate} + \text{Direct Overhead Rate})}{\text{Batch Size}}$$

Amortized batch setup is a function of the following:

- Machine setup time (specified as a machine property)
- Machine labor rate (specified as a machine property)
- Direct overhead rate (see [Direct and Indirect Overhead](#))

$$\text{Process Yield} = 1 / (\text{Machine Process Yield}/100)$$

Process yield depends on the machine property **Process Yield**.

Cycle Time Calculation

$$\text{Cycle Time} = \text{Load and Unload Time} + \text{Number of Bends} * (\text{Bending Time} + \text{Part Manipulation Time})$$

Cycle time depends on the following:

- Load and unload time (obtained from lookup table—see below; increases with part mass, which increases with material density).
- Number of bends (obtained from GCD extraction)
- Bending time (specified as a machine property)
- Part manipulation time (obtained from lookup table—see below; increases with part mass, which increases with material density)

Load and unload times and manipulation times by part mass are contained in the lookup table **bendBrakeHandling**.

Compression Bending

aPriori uses the formulas below to determine costs associated with this bending process.

Accounting Calculations

$$\text{Labor Time} = \text{Cycle Time} * \text{Machine Labor Time Standard} * \text{Machine Labor Ratio}$$

Labor time is the product of the following

- Cycle time (see [Cycle Time Calculation](#))
- Machine labor time standard (specified as a machine property). This value reflects the amount of time spent by machine operators in between machine cycles, including time performing maintenance and cleaning tasks as well as time pausing between tasks. The amount is expressed as a cycle time multiplier.
- Machine labor ratio (specified as a machine property)

$$\text{Labor Cost} = ((\text{Labor Time} / 3600) * \text{Machine Labor Rate}) / \text{Process Yield}$$

Labor cost is a function of the following:

- Labor time (see formula above)
- Machine labor rate (specified as a machine property)
- Process yield (see formula below)

Amortized Batch Setup =

$$(\text{Machine Setup Time} * (\text{Machine Labor Rate} + \text{Direct Overhead Rate})) / \text{Batch Size}$$

Amortized batch setup is a function of the following:

- Machine setup time (specified as a machine property)
- Machine labor rate (specified as a machine property)
- Direct overhead rate (see [Direct and Indirect Overhead](#))

$$\text{Process Yield} = 1 / (\text{Machine Process Yield}/100)$$

Process yield depends on the machine property **Process Yield**.

Cycle Time Calculation

$$\text{Cycle Time} = \text{Load and Unload Time} + \text{Number of Bends} * ((\text{Bending Time} + \text{Orientation Time}) / \text{Machine Number of Die Heads})$$

Cycle time depends on the following:

- Load and unload time (obtained from lookup table—see below; increases with part mass, which increases with material density).
- Number of bends (obtained from GCD extraction)
- Bending time (specified as a machine property, **Non Mandrel Bend Time**)
- Orientation time (obtained from lookup table—see below; increases with part mass, which increases with material density)
- Machine number of die heads (specified as a machine property)

Load and unload times and manipulation times by part mass are contained in the lookup table **compressionBendingHandling**.

Rotary Draw Bending

aPriori uses the formulas below to determine costs associated with this bending process.

Accounting Calculations

$$\text{Labor Time} = \text{Cycle Time} * \text{Machine Labor Time Standard} * \text{Machine Labor Ratio}$$

Labor time is the product of the following

- Cycle time (see [Cycle Time Calculation](#))
- Machine labor time standard (specified as a machine property). This value reflects the amount of time spent by machine operators in between machine cycles, including time performing maintenance and cleaning tasks as well as time pausing between tasks. The amount is expressed as a cycle time multiplier.
- Machine labor ratio (specified as a machine property)

$$\text{Labor Cost} = ((\text{Labor Time} / 3600) * \text{Machine Labor Rate}) / \text{Process Yield}$$

Labor cost is a function of the following:

- Labor time (see formula above)
- Machine labor rate (specified as a machine property)
- Process yield (see formula below)

$$\text{Amortized Batch Setup} = (\text{Machine Setup Time} * (\text{Machine Labor Rate} + \text{Direct Overhead Rate})) / \text{Batch Size}$$

Amortized batch setup is a function of the following:

- Machine setup time (specified as a machine property)
- Machine labor rate (specified as a machine property)
- Direct overhead rate (see [Direct and Indirect Overhead](#))

$$\text{Process Yield} = 1 / (\text{Machine Process Yield}/100)$$

Process yield depends on the machine property **Process Yield**.

Cycle Time Calculation

Cycle Time = Load and Unload Time + Number of Bends * (Bending Time + Rotate Time + Axial Traverse Time)

Cycle time depends on the following:

- Load and unload time (obtained from lookup table—see below; increases with part mass, which increases with material density).
- Number of bends (obtained from GCD extraction)
- Bending time (specified as a machine property, **Mandrel Bend Time** or **Non Mandrel Bend Time**)
- Rotate time, which depends on the following:
 - Number of changes in bend angles
 - Machine property **Clock Angle Rotate Time**
- Axial traverse time, which depends on the following:
 - Distance between bends
 - Machine property **Axial Feed Rate**

Load and unload times and manipulation times by part mass are contained in the lookup table **rotaryDrawBendingHandling**.

See [User Inputs](#) for information on mandrel bending.

Forming

The calculations described in this section cover the cost models for the following processes:

- **Expansion**
- **Flanging**
- **Flaring**
- **Flattening**
- **Knurling**
- **Notching**
- **Reduction**
- **Slotting**

aPiori uses the formulas below to determine costs associated with these forming processes.

Accounting Calculations

Labor Time = Cycle Time * Machine Labor Time Standard * Machine Labor Ratio

Labor time is the product of the following

- Cycle time (see [Cycle Time Calculation](#))
- Machine labor time standard (specified as a machine property). This value reflects the amount of time spent by machine operators in between machine cycles, including time performing maintenance and cleaning tasks as well as time pausing between tasks. The amount is expressed as a cycle time multiplier.
- Machine labor ratio (specified as a machine property)

$$\text{Labor Cost} = ((\text{Labor Time} / 3600) * \text{Machine Labor Rate}) / \text{Process Yield}$$

Labor cost is a function of the following:

- Labor time (see formula above)
- Machine labor rate (specified as a machine property)
- Process yield (see formula below)

$$\text{Amortized Batch Setup} = (\text{Machine Setup Time} * (\text{Machine Labor Rate} + \text{Direct Overhead Rate})) / \text{Batch Size}$$

Amortized batch setup is a function of the following:

- Machine setup time (specified as a machine property)
- Machine labor rate (specified as a machine property)
- Direct overhead rate (see [Direct and Indirect Overhead](#))

$$\text{Process Yield} = 1 / (\text{Machine Process Yield}/100)$$

Process yield depends on the machine property **Process Yield**.

Cycle Time Calculation

$$\text{Cycle Time} = \text{Machine Load Time} + \text{Machine Unload Time} + \text{Form Cycle Time}$$

Cycle time is the sum of the following machine properties:

- Machine Load Time
- Machine Unload Time
- Form cycle time depends on the following
 - Number of formed features
 - Machine property **End Form Cycle Time**

Laser Cut, Oxy Fuel Cut, Plasma Cut

aPriori uses the formulas below to determine costs associated with these cutting processes (used for plate rolling).

Accounting Calculations

$$\text{Labor Time} = \text{Cycle Time} * \text{Machine Labor Time Standard}$$

Labor time is the product of the following

- Cycle time (see [Cycle Time Calculation](#))
- Machine labor time standard (specified as a machine property). This value reflects the amount of time spent by machine operators in between machine cycles, including time performing maintenance and cleaning tasks as well as time pausing between tasks. The amount is expressed as a cycle time multiplier.

$$\text{Labor Cost} = (\text{Labor Time} / 3600) * \text{Machine Labor Rate}$$

Labor cost is a function of the following:

- Labor time (see formula above)
- Machine labor rate (specified as a machine property)

Direct Overhead Cost = (Cycle Time / 3600) * Machine Overhead Rate

Direct overhead cost depends on the following:

- Cycle time (see formula below)
- Machine overhead rate (specified as a machine property)

Amortized Batch Setup =

$$\frac{\text{Machine Setup Time} * (\text{Machine Labor Rate} + \text{Direct Overhead Rate})}{\text{Batch Size}}$$

Amortized batch setup is a function of the following:

- Machine setup time (specified as a machine property)
- Machine labor rate (specified as a machine property)
- Direct overhead rate (see [Direct and Indirect Overhead](#))

Cycle Time Calculation

$$\frac{\text{Cycle Time} = (\text{Burn Time} + \text{Pierce Time} + \text{Rapid Traverse Time} + \text{Scrap Cutting Time} + \text{Shuttle Time})}{\text{Machine Number of Heads}}$$

Cycle depends on the following:

- Burn time, which depends on the following:
 - Cross-section thickness
 - Material type—aluminum, for example, cuts faster than steel
 - Machine wattage
 - Blank size
 - Feature perimeters—burn time increases with hole size.
 - Feature radii of curvature—tighter cuts are slower.
- Pierce time, which depends on the following:
 - Number of holes
 - Cross-section thickness
 - Material type
 - Machine wattage
- Rapid traverse time, which depends on the following:
 - Blank size
 - Machine's rapid traverse feed rate
- Scrap cutting time
- Shuttle time (increases with blank size)
- Machine number of heads (specified as a machine property)

Pierce and burn cutting rates by machine watts and material type and thickness are contained in the following lookup tables:

- **Laser smNestingCutRate**
- **Plasma smNestingCutRate**
- **OxyFuel smNestingCutRate**

Shear

aPriori uses the formulas below to determine costs associated with this cutting process.

Accounting Calculations

Labor Time = Cycle Time * Machine Labor Time Standard

Labor time is the product of the following

- Cycle time (see [Cycle Time Calculation](#))
- Machine labor time standard (specified as a machine property). This value reflects the amount of time spent by machine operators in between machine cycles, including time performing maintenance and cleaning tasks as well as time pausing between tasks. The amount is expressed as a cycle time multiplier.

Labor Cost = (Labor Time / 3600) * Machine Labor Rate

Labor cost is a function of the following:

- Labor time (see formula above)
- Machine labor rate (specified as a machine property)

Amortized Batch Setup = Machine Setup Time * Machine Labor Rate

Amortized batch setup is a function of the following:

- Machine setup time (specified as a machine property)
- Machine labor rate (specified as a machine property)

Cycle Time Calculation

Cycle Time = (1 / Machine Cut Speed) + Handling Time

Cycle time depends on the following:

- Machine cut speed
- Handling time (obtained from the lookup table `smShearHandling`, increases with part mass, which increases with material density)

Roll Bending (2-, 3-, and 4-roll)

aPriori uses the formulas below to determine costs associated with this bending process (used for plate rolling).

Routing

Roll Bending in the **Bar & Tube Fab** process group applies only to 360 degree tubes, and only applies to round tube cross sections. At large diameters and very thick tubes, round tubes are recognized as round bars, which causes sheet stock to fail. See *Process Group Site Variables* on [page 242](#) for information about controlling this calculation.

Accounting Calculations

Expendable Tooling Cost -- unused

Setup Cost = (Setup Time per Part * Labor Rate) + (Setup Time per Part * Overhead Rate)

Labor Cost = Labor Rate * Labor Time / 3600 (seconds per hour)

Overhead Cost = (Labor Cost * Overhead Multiplier) + (Overhead Rate * Cycle Time / 3600)

Cycle Time Calculation (2-Roll Bending)

Cycle Time = Part Handling Time + Rolling Time

Cycle time for 2-Roll Bending is the product of the following:

- Rolling Time = (Part Cross-Section Sheet Width)/(Setup Rolling Speed)
 - Rolling Speed = Machine Rolling Speed
- Note:** If yield strength reaches 90 % of ultimate tensile strength, then:
Rolling Speed = (Machine Rolling Speed) * (Plant Rolling Speed Adjustment Factor)
- Part Handling Time = load time + unload time (times same as in Bend Brake)

Cycle Time Calculation (3- and 4-Roll Bending)

**Cycle Time = Part Handling Time + Rolling Time (Number of Passes + Number of Re-roll Passes) +
Prebend Time + Reroll Part Handling Time**

Cycle time for 3- and 4-Roll Bending is the product of the following:

- Rolling Time = (Part Cross-Section Sheet Width)/(Setup Rolling Speed)
 - Rolling Speed = Machine Rolling Speed
- Note:** If yield strength reaches 90 % of ultimate tensile strength, then:
Rolling Speed = (Machine Rolling Speed) * (Plant Rolling Speed Adjustment Factor)
- Part Handling Time = load time + unload time (times same as in Bend Brake)
 - Pre-bend Time = (2 * machine pre-bend)
- Note:** For 360 degree Roll Bending, each end is pre-bended to minimize flats.
- Number of passes: In 3- and 4-roll bending, some parts have to be rolled in multiple passes.

The component will be completed in one pass if:

Part Cross-Section Inside Diameter >= Minimum Single Pass Diameter

AND

Part Cross-Section Inside Diameter <= Minimum Multi Pass Diameter

AND

Part Cross-Section Thickness <= Minimum Single Pass Thickness

AND

Part Minimum Stock Length <= Single Pass Roll Length

Single Pass Roll Length depends upon the Material Strength Ratio.

If Material Strength Ratio <= 1, then

$$\text{Single Pass Roll Length} = (\text{Machine Roll Working Length}) * (\text{materialStrengthRatio}) * ((\text{Minimum Single Pass Diameter}) / (\text{Part Cross-section Inside Diameter}))$$

If Material Strength Ratio > 1, then

$$\text{Single Pass Roll Length} = (\text{Machine Roll Working Length}) * ((\text{Minimum Single Pass Diameter}) / (\text{Part Cross-section Inside Diameter}))$$

$$\text{Material Strength Ratio} = \text{sqrt}((\text{Machine Reference Yield Strength}) / (\text{Material Tensile Yield Strength}))$$

Note: Machine Maximum Working Length decreases when diameter increases and strength of material increases.

- Determining number of passes if greater > 1

The number of passes depends on the material springback, which increases with

- Higher yield strength
- High bend diameter to thickness ratio
- Bigger bend angle

$$\text{Number of Passes} = \text{Material Strength Pass} + \text{Diameter Thickness Pass} + \text{Bend Angle Pass} + \text{Additional Pass}$$

where:

Material Strength Pass = +1 if (Material Yield Strength) > Plant Reference Tensile Strength

Diameter Thickness Pass = + 2 (diameter to thickness was checked in the single pass rule above)

Bend Angle Pass = +1 (all tubes are 360 degrees, which is > 180)

Additional Pass = +1 if Part Thickness reaches 90% Machine Maximum Machine Thickness (to protect machine)

- Number of re-roll passes: Re-rolling occurs after rolling the part and welding the ends together. If you need to re-roll, you must specify the number of re-roll passes. If re-roll passes > 0, then Re-Roll Part Handling Time is Load Time + Unload Time.

3-Roller Bending (deprecated)

Note: See the depreciation notice regarding this process above at [Machines](#).

aPriori uses the formulas below to determine costs associated with this bending process (used for plate rolling).

Accounting Calculations

Labor Time = Cycle Time * Machine Labor Time Standard

Labor time is the product of the following

- Cycle time (see Cycle Time Calculation)
- Machine labor time standard (specified as a machine property). This value reflects the amount of time spent by machine operators in between machine cycles, including time performing maintenance and cleaning tasks as well as time pausing between tasks. The amount is expressed as a cycle time multiplier.

Labor Cost = (Labor Time / 3600) * Machine Labor Rate

Labor cost is a function of the following:

- Labor time (see formula above)
- Machine labor rate (specified as a machine property)

Amortized Batch Setup = Machine Setup Time * Machine Labor Rate

Amortized batch setup is a function of the following:

- Machine setup time (specified as a machine property)
- Machine labor rate (specified as a machine property)

Cycle Time Calculation

Cycle Time = Load Time + Unload Time + Rolling Time + Inspection Time

Cycle time depends on the following:

- Load time (obtained from lookup table—see below; increases with part mass, which increases with material density)
- Unload time (obtained from lookup table—see below; increases with part mass, which increases with material density)
- Rolling time (see formula below)
- Inspection time (see formula below)

Rolling Time = (Sheet Width * Number of Passes) / Rolling Rate

Rolling time depends on the following:

- Sheet width (obtained from GCD extraction)
- Number of passes (linear function using the ratio of bend diameter to part thickness—the ratio must be less than 20; number of passes capped at 10)
- Rolling rate (specified as a machine property)

Number of Passes = Linear function using ratio of Bend Diameter to Part Thickness (Diameter Thickness Ratio must be less than 20. Number of Passes capped at 10.)

Inspection Time = (Load Time + Unload Time + Rolling Time) * Hourly Inspection Rate

Inspection time depends on the following:

- Load time (obtained from lookup—see below; increases with part mass, which increases with material density)
- Unload time (obtained from lookup table—see below; increases with part mass, which increases with material density)
- Rolling time (see formula above)
- Hourly inspection rate (based on plant variable **inspectionMinPerHour**)

Load and unload times by part mass are contained in the lookup table **rollingHandling**.

Extrusion

The following sections cover the formulas and calculations for the Extrusion process:

- Material Cost and Utilization
- Cycle Time
- Maximum Acceptable Ram Speed
- Reduced Max Ram Speed
- Number of Die Cavities
- Maximum Number of Die Cavities
- Part Complexity Reduction Factor
- Class Complexity Score
- Tongue Complexity Score
- Critical Tongue Ratio
- Quench Speed Reduction Factor
- Billet Size and Parts per Billet
- Hard Tooling Cost

Material Cost and Utilization

Material Cost = Raw Material Cost – Scrap Material Credit – Scrap Part Credit

Material Cost depends on the following:

- Raw material cost: see formula.
- Scrap material credit: this is 0 if the setup option **Enable Scrap Material Credit** is set to **false**. Otherwise, it is given by the formula below.
- Scrap part credit: this is 0 if the setup option **Enable Scrap Part Credit** is set to **false**. Otherwise, it is given by the formula below.

Raw Material Cost = (Rough Mass * Cost per Kg) / Final Yield

Raw material cost depends on the following:

- Rough mass: see formula.

-
- Cost per KG: specified by **Round Bar Unit Cost** in the material table.
 - Final yield: see [Yields for Bar & Tube Fabrication](#)

Rough Mass = Finish Mass / Utilization

Rough mass depends on the following:

- Finish mass: product of material density and the geometric property **Volume** for the part.
- Utilization: see formula.

Utilization = Extrusion Utilization * Non-extrusion Utilization

Utilization depends on the following:

- Extrusion utilization: this reflects the fraction of billet material that ends up as extruded stock. See formula below.
- Non-extrusion utilization: this reflects the fraction of extruded stock that ends up in parts in their final form. See the formula for Utilization in [Material Cost and Utilization](#).

Extrusion Utilization =

$$\frac{(\text{Batch Size} * \text{Part Length} * \text{Part Cross-sectional area})}{(\text{Billet Volume} * \text{Billets Needed per Batch})}$$

Utilization depends on the following:

- Batch size: specified in the Production Scenario tab of the Cost Guide.
- Part length: specified by the geometric property **Length** for the part's CrossSection GCD.
- Part cross-sectional area: specified by the geometric property **Area** for the CrossSection GCD.
- Billet volume: see [Billet Size and Parts per Billet](#).
- Billets needed per batch: see [Billet Size and Parts per Billet](#).

Scrap Material Credit = Material Cost per Kg * Scrap Cost Fraction * Scrap Mass

Scrap material credit is 0 if the setup option [Enable Scrap Material Credit](#) is set to **false**. Otherwise, it is the product of the following:

- Material cost per KG: specified by the material property **Round Bar Unit Cost**.
- Scrap cost fraction: specified as percentage by the material property **Scrap Cost Percent**.
- Scrap mass: see formula

Scrap Mass = Rough Mass – Finish Mass

Scrap mass depends on the following:

- Rough mass: see formula.
- Finish mass: product of material density and the geometric property **Volume** for the part.

Scrap Part Credit =

$$\frac{(\text{Material Cost per Kg} * \text{Scrap Cost Fraction}) * ((\text{Number of Scrap Parts} + \text{Number of Scrap Parts Down Stream}) * \text{Rough Mass})}{\text{Total Production Volume}}$$

Scrap part credit is 0 if the setup option [Enable Scrap Part Credit](#) is set to **false**. Otherwise, it is the product of the following:

- Material cost per mass: specified by the material property **Cost per KG**.
- Scrap cost fraction: this is 0 if the setup option is un-checked (the default in starting point VPEs). Otherwise, it is specified as a percentage by the material property **Scrap Cost Percent**.
- Number of scrap parts: number of parts discarded as scrap by this process. See [Yields for Bar & Tube Fabrication](#).
- Number of scrap parts down stream: number of parts discarded as scrap by downstream processes. See [Yields for Bar & Tube Fabrication](#).
- Rough mass: see formula
- Total production volume: specified in the Production Scenario tab of the Cost Guide.

Cycle Time

$$\text{Cycle Time} = \text{Process Time} * \text{Cycle Time Adjustment Factor}$$

Cycle time is the product of the following:

- Process time: see formula.
- Cycle time adjustment factor: specified by the cost model variable **cycleTimeAdjustmentFactor** (1 in starting point VPEs). Administrators can customize this value in order to globally adjust cycle times for this process group.

$$\text{Process Time} = \text{Billet Process Time} / \text{Parts Per Billet}$$

Process time depends on the following:

- Billet process time: this is the time to extrude one billet of material.
- Parts per billet: this is the number of parts that are produce from a single billet. See [Billet Size and Parts per Billet](#).

$$\text{Billet Process Time} =$$

$$\text{Dead Cycle Time} + \text{Contact Time} + \text{Die Change Time Per Billet}$$

Billet process time is the sum of the following:

- Dead cycle time: the time required to reset the ram and load a new billet, specified by the machine property **Ram Reset Time**.
- Contact time: the time in a single cycle during which the ram is in contact with the billet. See formula.
- Die change time per billet: this the time required to change the die, amortized over the number of billets that can be processed before a change of die is necessary. See formula.

Note that the extrusion process is assumed to be balanced, so that various activities are performed in parallel with the activities listed above, including stretching, cutting, racking, transporting, and applying release agent. Since they are performed in parallel, they do not add to the cycle time.

Contact Time = Billet Length / Ram Speed

Contact time depends on the following:

- Billet length: the length of the billet used depends on a variety of factors, including the size of the production batch and the number of cavities in the die. See [Billet Size and Parts per Billet](#).
- Ram speed: ram speed depends on a number of factors, including part complexity and acceptable exit speed range for the current material. See [Maximum Acceptable Ram Speed](#).

Die Change Time Per Billet = Die Change Time / Number Billets Per Die

Die change time per billet is the time required to change the die, amortized over the number of billets that can be processed before a change of die is necessary. It depends on the following:

- Die change time: this depends on the die diameter (see formula). It is a multiple of the tool shop variable **Base Die Loading Time**:
 - If the die diameter \leq tool shop variable **DieDiameterLowerLimitForChangeTime**, the multiple is 1.
 - If the die diameter is between tool shop variables **dieDiameterLowerLimitForChangeTime** and **dieDiameterUpperLimitForChangeTime**, the multiple is 2.
 - If the die diameter \geq tool shop variable **dieDiameterUpperLimitForChangeTime**, the multiple is 3.
- Number of billets per die: see formula.

Number of Billets Per Die =

$$\frac{(\text{Tool Final Crack Length}^{(1 - (\text{Tool Paris Exponent} / 2))} - \text{Tool Existing Crack Length}^{(1 - (\text{Tool Paris Exponent} / 2))})}{(\text{Tool Paris Constant} * ((\text{Tool Paris Exponent} / 2) - 1) * (\text{Tool Edge Crack Geometry Factor}^{\text{Tool Paris Exponent}} * (\text{Pi}^{(\text{Tool Paris Exponent} / 2))} * (\text{Tool Max Stress}^{\text{Tool Paris Exponent}}))}$$

This formula evaluates strain crack propagation. Based on this evaluation, the number of billets per die depends on the following:

- Tool final crack length: see formula.
- Tool Paris exponent: specified by the tool shop variable **Paris Exponent**.
- Tool existing crack length: specified by the tool shop variable **Existing Crack Length**
- Tool Paris constant: specified by the tool shop variable **Paris Constant**.
- Tool edge crack geometry factor: specified by the tool shop variable **Edge Crack Geometry Factor**.
- Tool max stress: see formula.

$$\text{Tool Final Crack Length} = 1 / \text{PI} * (\text{Tool Material Fracture Toughness} / (\text{Tool Edge Crack Geometry Factor} * \text{Tool Max Stress}))^2$$

Tool final crack length depends on the following:

- Tool material fracture toughness: specified by the tool shop variable **Tool Material Fracture Toughness**.
- Tool edge crack geometry factor: specified by the tool shop variable **Edge Crack Geometry Factor**.
- Tool max stress: see formula.

$$\text{Tool Max Stress} = \text{Required Pressure} * (\text{Tool Die Radius}^2 + \text{Encompassed Circle Radius}^2) / (\text{Tool Die Radius}^2 - \text{Encompassed Circle Radius}^2)$$

Tool max stress depends on the following:

- Tool die radius: half the tool die diameter—see formula.
- Encompassed circle radius: this half the value of the geometric property **Max Thickness** for the **CrossSection GCD**.

$$\text{Tool Die Diameter} = \text{Billet Diameter} * \text{Tool Die Diameter Adjustment Factor}$$

Tool die diameter depends on the following:

- Billet diameter: specified by the machine property **Billet Diameter**.
- Tool diameter adjustment factor: specified by the tool shop variable **Die Diameter Adjustment Factor**.

Maximum Acceptable Ram Speed

The maximum acceptable ram speed for each machine is calculated in order to guide machine selection (see [Machine Selection for Extrusion](#)). The maximum acceptable ram speed for the selected machine is also used to calculate cycle time (see [Cycle Time](#)).

For a given machine, acceptable ram speeds are constrained by a number of factors:

- Ram speed must result in an exit speed that is within range for the current material, as specified by the following:
 - Material property **Minimum Extrusion Exit Speed**
 - Material property **Maximum Extrusion Exit Speed**
- Ram speed must be slow enough to prevent deformation, taking into account both the following:
 - [Part Complexity Reduction Factor](#)
 - [Number of Die Cavities](#)
- Ram speed must be slow enough to result in a balanced process, given the current [Quench Type](#). Longer quench times require slower ram speeds.
- Ram speed is bounded above by the machine property **Max Ram Speed**.

For a given machine, aPriori does the following to calculate maximum acceptable ram speed:

1. Find the maximum number of cavities that can fit in the die. See [Maximum Number of Die Cavities](#).

2. Adjust the machine's **Max Ram Speed** downward in order to account for part complexity and quench type. See [Reduced Max Ram Speed](#).

3. Consider a die with each possible number of cavities, n , that can fit in the die. For example, if [Maximum Number of Die Cavities](#) is 3, consider a die with 3 cavities, a die with 2 cavities, and a die with 1 cavity. For each one, do the following:

Find the highest ram speed, S_n , that results in an in-range exit speed.

If S_n is not greater than [Reduced Max Ram Speed](#), S_n is the maximum acceptable ram speed. If the current machine is selected, the ram speed is assumed to be S_n , and the number of die cavities is assumed to be n .

Otherwise, if [Reduced Max Ram Speed](#) results in an exit speed that is not less than the material's **Minimum Extrusion Exit Speed**, [Reduced Max Ram Speed](#) is the maximum acceptable ram speed. If the current machine is selected, the ram speed is assumed to be [Reduced Max Ram Speed](#), and the number of die cavities is assumed to be n .

The cost model finds, for a die with a given number of cavities, the highest ram speed that results an in-range exit speed by calculating the ram speed that results in the material's **Maximum Extrusion Exit Speed**:

Max Material Ram Speed = Material Max Exit Speed / Extrusion Ratio

Max material ram speed depends on the following:

- Material max exit speed: this is the value of the material property **Maximum Extrusion Exit Speed**.
- Extrusion ratio: this is the ratio of the billet area to the total cross-sectional area of the extrudate. See the formula below.

Extrusion Ratio =

Billet Area / (Number of Die Cavities * Part Cross-sectional Area)

Extrusion ratio depends on the following:

- Billet area: this is determined by the machine property **Billet Diameter**.
- Number of die cavities: this is the number of die cavities currently under consideration.
- Part cross-sectional area: this is the value of the geometric property **Area** for the CrossSection GCD.

The cost model finds the exit speed that results from [Reduced Max Ram Speed](#) as follows:

Exit Speed = Reduced Max Ram Speed * Extrusion Ratio

Exit speed, in this case, depends on the following:

- [Reduced Max Ram Speed](#)
- Extrusion ratio: see formula above

Reduced Max Ram Speed

As part of calculating [Maximum Acceptable Ram Speed](#), aPriori adjusts the machine's **Max Ram Speed** downward, in order to account for part complexity and quench type. The cost model uses the following formula:

**Reduced Max Ram Speed = Machine Max Ram Speed *
Part Complexity Reduction Factor * Quench Speed Reduction Factor**

Reduced max ram speed is the product of the following:

- Machine max ram speed: specified by the machine property **Max Ram Speed**.
- Part Complexity Reduction Factor.
- Quench Speed Reduction Factor.

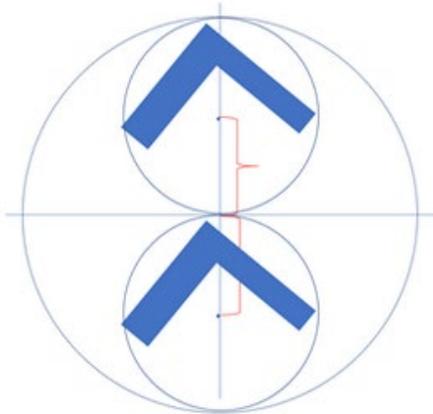
Number of Die Cavities

By default, the cost model assumes that the number of die cavities is the number of die cavities that results from the calculation of the **Maximum Acceptable Ram Speed** for the selected machine. This value is bounded above by **Maximum Number of Die Cavities**. Users can override the default with the setup option **Number of Cavities in Die**, but the override does not affect machine selection or the determination of the maximum acceptable ram speed.

Maximum Number of Die Cavities

This section discusses the calculation of the maximum number of cavities than can fit in the die. This quantity is used to help determine the **Maximum Acceptable Ram Speed** and the **Number of Die Cavities**.

For parts extruded at the same time, the centroid of the extrusions must be equidistant from the die centroid, as in the illustration below.



Because of this, the cost model determines the maximum number of cavities that can fit in a die as follows:

- 1 Determine the radius of the usable area of the die. This is the radius of the die face minus a clearance allowance. These radii and clearance values are determined as follows:
 - Radius of the die face is given by half the product of the machine property **Billet Diameter** and the tool shop variable **Die Diameter Adjustment Factor**. Note that since the pockets in the die allow material to flow outside the billet diameter, die diameter can exceed billet diameter.
 - Clearance allowance is looked up in the lookup table **tblStandardSizes**. It is given by the value in the Size column for the row that has

dieODClearanceForNesting in the Variable column and the current system units (**US** or **metric**) in the Unit column.

- 2 Determine the radius, r , of a die cavity's smallest enclosing circle (SEC). This is the radius of the part cross section's smallest enclosing circle, given by half the value of the geometric property **Outside Diameter** for the CrossSection GCD. The radius r is shown in red in the figure at the end of this section.
- 3 Determine the maximum number of SECs of radius r that can fit within the usable die area. Assume that each SEC (if more than one fits) is tangent to the edge of the usable die area as well as tangent to an adjacent SEC (see the diagram).

The number of circles that can fit can be determined from the angle, X , formed by the following two line segments:

- Line segment from the center of the usable die area to the center of an SEC
- Line segment from the center of the usable die area to the point at which the SEC is tangent to an adjacent SEC

Each SEC lies on a certain fraction of the circle (shown in black in the figure) whose center is the center of the usable die area and whose radius, R (shown in blue in the figure), is the difference between the radius of the usable die area and the radius, r , of an SEC. The fraction, f , of the black circle that is occupied by each SEC is $(2 * X) / (2 * \text{Pi})$. So the maximum number of SECs that can lie on the black circle (without overlapping) is given by the following:

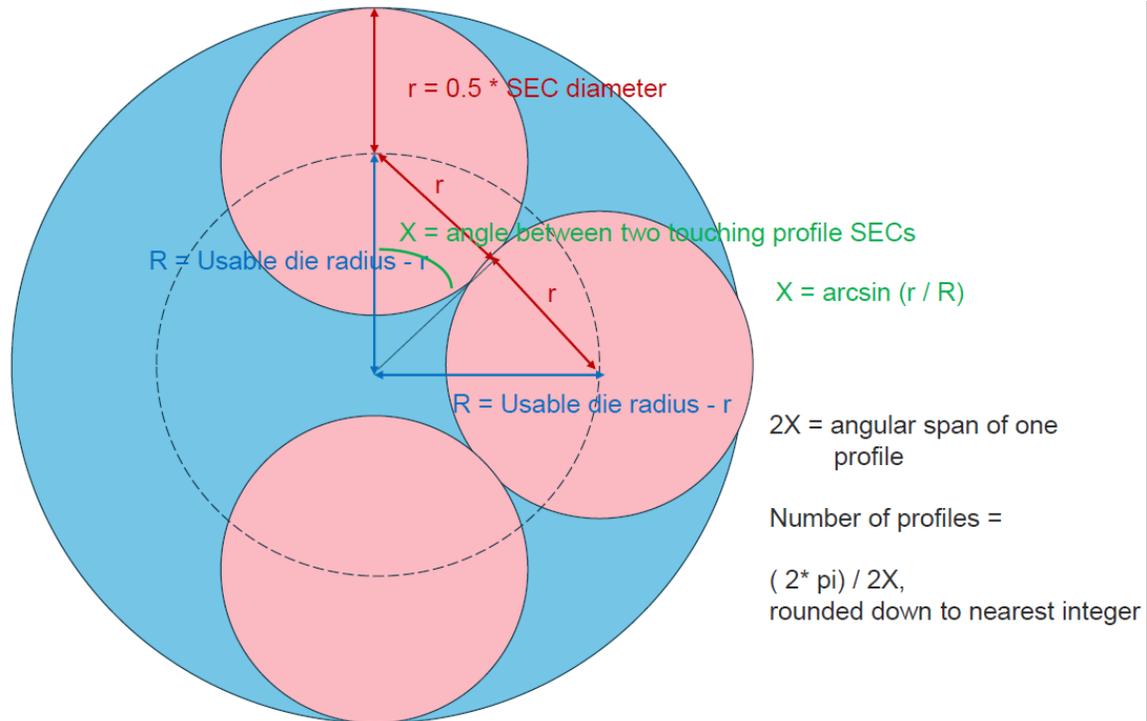
Max Number of Die Cavities = rounddown($(2 * \text{Pi}) / (2 * X)$)

The angle X can be determined from the SEC radius, r , and the black circle radius, R . X is the angle opposite the side of length r in the right triangle formed by the following line segments:

- Line segment (shown in blue) of length R from the center of the usable die area to the center of an SEC. This is the hypotenuse.
- Line segment from the center of the usable die area to the point at which the SEC is tangent to an adjacent SEC. This is the side adjacent to X .
- Line segment (shown in red) of length r from the center of the SEC to the point at which the SEC is tangent to an adjacent SEC. This is the side opposite X .

Note that the last two line segments form a right angle, since a line tangent to a circle at a given point is perpendicular to the radius that ends at that point. Therefore, X is given by the following:

$$X = \arcsin(r / R)$$



The final value for maximum number of cavities is bounded above by the value of the cost model variable **maxStandardNestedPartsOnDie** (6 in starting point VPEs). That is, if the calculated value **Max Number of Die Cavities** (above) exceeds the value of **maxStandardNestedPartsOnDie**, the value of **maxStandardNestedPartsOnDie** is used instead.

Part Complexity Reduction Factor

Part complexity factor is used to determine the **Maximum Acceptable Ram Speed**. This factor is used to adjust the machine maximum ram speed in order to ensure that no deformation occurs during extrusion.

The complexity factor is bounded below by 0.1. More complex parts have *lower* complexity factors (and thus effect a greater reduction in the machine's maximum ram speed).

$$\text{Part Complexity Reduction Factor} = \max(0.1, 1 - (\text{Complexity Score} / 10))$$

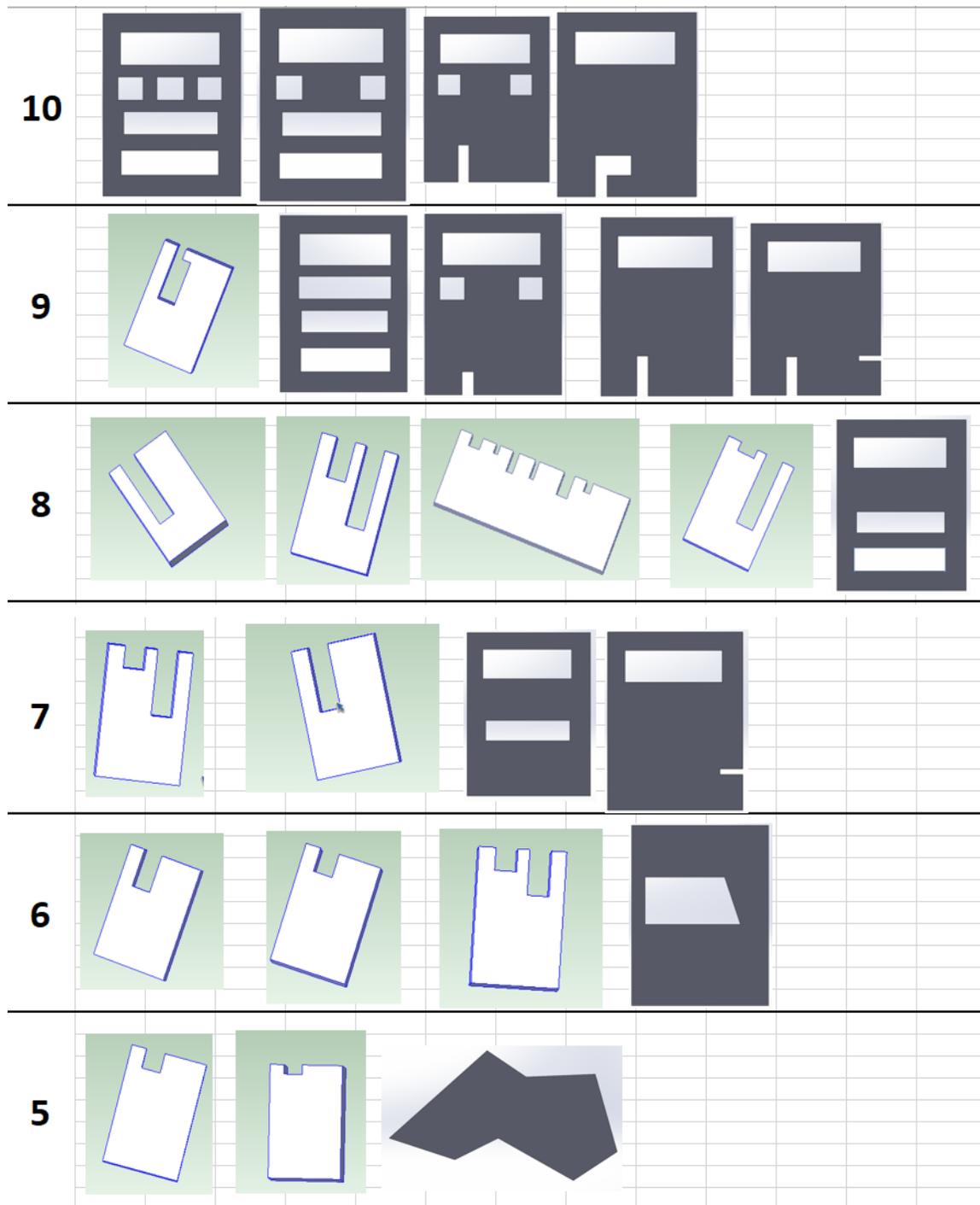
The complexity score is bounded above by 10. More complex parts have *higher* complexity scores.

$$\text{Complexity Score} = \min(10, \text{Class Complexity Score} + \text{Tongue Complexity Score})$$

A part's class complexity score is higher if there are CrossSectionHollow GCDs present, especially fully hollow or asymmetric ones. In the absence of CrossSectionHollow GCDs, thinner parts have a higher class complexity score than thicker ones. See **Class Complexity Score**.

A part's tongue complexity score is higher for a part with a higher **Critical Tongue Ratio**. See **Tongue Complexity Score**.

Below are some sample cross sections arranged from most to least complex:



Class Complexity Score

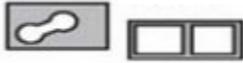
A part's class complexity score depends on the characteristics of CrossSectionHollow GCDs present in the part or on the maximum thickness of the part cross section.

A CrossSectionHollow is a region of the part's cross section for which one of the following holds:

- Fully hollow: region is bounded by an internal contour of the cross section.

-
- Semi-hollow: region is not occupied by the part and is surrounded, except for a small gap, by part of the external contour of the cross section.

The cross sections shown below have fully hollow regions:



The cross sections shown below have semi-hollow regions:



Note that the first two semi-hollow regions are symmetric, and the last one is asymmetric. The geometric property **Symmetric** indicates whether a CrossSectionHollow is symmetric.

The class complexity score is determined by cases:

- Fully hollow
If there is at least one fully hollow CrossSectionHollow, class complexity score is **6 + (Number of Fully hollow CrossSectionHollows - 1)**
- Asymmetric Semi-hollow
Otherwise, if there is at least one asymmetric semi-hollow CrossSectionHollow, class complexity score **6**.
- Symmetric Semi-hollow
Otherwise, if there is at least one (symmetric) semi-hollow CrossSectionHollow, class complexity score **5**.
- No Hollows, Thin Cross Section
Otherwise, if the **Max Thickness** of the CrossSection GCD is less than 1.016mm, class complexity score is **6**.
- No Hollows, Thick Cross Section
Otherwise, class complexity score is **5**.

Tongue Complexity Score

If T is the part's [Critical Tongue Ratio](#), tongue complexity score is determined as follows:

- If $T > 3$, tongue complexity score is **3**.
- Otherwise, if $T > 2$, tongue complexity score is **2**.
- Otherwise, if $T > 1$, tongue complexity score is **1**.
- Otherwise, tongue complexity score is **0**.

Critical Tongue Ratio

The tongue ratio of a semi-hollow CrossSectionHollow GCD (see [Class Complexity Score](#)) depends on the geometric properties **Area** and **Gap Length**. (Fully hollow CrossSectionHollow GCDs have a **Gap Length** of 0.) Tongue ratio is the ratio of the **Area** to the square of the **Gap Length**:

Tongue Ratio = Area / (Gap Length)²

The critical tongue ratio of a part is the tongue ratio of the CrossSectionHollow with the *largest* tongue ratio.

Critical Tongue Depth

The tongue depth of a semi-hollow CrossSectionHollow GCD (see [Class Complexity Score](#)) depends on the geometric properties **Perimeter** and **Gap Length**. (Fully hollow CrossSectionHollow GCDs have a **Gap Length** of 0.) Tongue depth is the difference between the **Perimeter** and twice the **Gap Length**:

Tongue Depth = Perimeter – (2 * Gap Length)

The critical tongue depth of a part is the tongue depth of the CrossSectionHollow with the *largest* tongue depth.

Critical tongue depth is 0 for a part with no semi-hollow CrossSectionHollow GCDs.

Quench Speed Reduction Factor

Quench speed reduction factor (see [Reduced Max Ram Speed](#)) depends on the current [Quench Type](#):

- Standing Wave Quench: 1
- Water Spray Quench: 0.77
- Air Quench: 0.385

Billet Size and Parts per Billet

This section discusses the calculation of four quantities:

- Number of parts per billet
- Billet length
- Billet volume
- Number of billets needed per batch

One or more of these quantities are used in a variety of calculations, including the following:

- [Machine Selection for Extrusion](#)
- [Material Cost and Utilization](#)
- [Cycle Time](#)
- [Hard Tooling Cost](#)

By default, the quantities are determined as described in steps 1-6, below. If the setup option [Billet Length](#) overrides the default, they are calculated as described in step 7, below.

1. Determine the volume of the largest standard billet for the current machine. This depends on the following:

- Value of the machine property **Max Billet Length**.
- Current unit system (**Metric** or **US**).
- Value of the machine property **Billet Diameter**.

2. Calculate the maximum number of parts that can be produced by such a billet. This depends on the volumes of the following:

- Extrudate needed per part: this is the extruded part volume plus the parting scrap, which is scrap that results from separation of the parts from one another. This includes scrap whose total volume is proportional to the number of parts per billet; it does *not* include butt scrap, weld scrap, and trim scrap (see below).
- Butt scrap: this is the unusable material that builds up at the end of the billet during the extrusion.
- Weld scrap: this scrap is produced when a billet loaded into the press fuses with the remainder of the previous billet. Weld scrap volume is 0 if only one billet is required for a production batch. It is also 0 if the setup option **Weld Scrap Included** is set to **false**.
- Trim scrap: this is material at either end of the extrudate that is crushed during stretching or transporting.
- **Number of Die Cavities**

This step determines the maximum number of parts than can fit on a billet, given the number of cavities and the machine constraints on billet size. This provides an upper bound on the number of parts per billet assumed by the cost model.

3. Determine the number of billets required to produce one production batch, given that the number of parts produced from each billet is the quantity found in step 2. This depends on the following:

- Quantity found in step 2
- Production batch size

This is the minimum possible number of billets required for a production batch, given the machine constraints on billet size. The cost model assumes that this number of billets is used for each batch, provided this assumption results in a billet length that is greater than or equal to the machine's **Min Billet Length** (see steps 5-7).

4. Determine the number of parts per billet, assuming that the parts in a production batch are evenly distributed across all the billets needed for the batch. This depends on the following quantities:

- Quantity found in step 3
- Production batch size
- **Number of Die Cavities**

This might result in fewer parts per billet than found in step 2, and so result in a smaller billet size. The cost model assumes that the number of parts produced by each billet is the value found in this step, provided that this assumption results in a billet length that is greater than or equal to the machine's **Min Billet Length** (see steps 5-6).

5. Determine the volume and length of the smallest billet that can yield the number of parts found in step 4. This depends on the following:

- Quantity found in step 4
- Extrudate needed per part
- Butt scrap volume

-
- Weld scrap volume
 - Trim scrap volume
 - Billet diameter

If Billet Length is greater than or equal to the Machine's **Min Billet Length**, stop here.

6. If Billet Length is less than the Machine's **Min Billet Length**, the billet length is assumed to be **Min Billet Length**. The Billet Volume is assumed to be given by the following:

Min Billet Volume = Min Billet Length * Billet Area

Number of parts per billet depends on the following:

- Min Billet Length
- Butt scrap volume
- Weld scrap volume
- Trim scrap volume
- Extrudate needed per part

The number of billets needed for a batch depends on the following:

- Production batch size
- Number of parts per billet

7. If the user overrides the calculated billet length with the setup option **Billet Length**, calculations like those in step 7 are performed:

Custom Billet Volume = Custom Billet Length * Billet Area

Number of parts per billet is depends on the following:

- Custom Billet Length
- Butt scrap volume
- Weld scrap volume
- Trim scrap volume
- Extrudate needed per part

The number of billets needed for a batch depends on the following:

- Production batch size
- Number of parts per billet

Hard Tooling Cost

The formulas below show the cost for one die. An evaluation of strain crack propagation is used to determine tool life—see the formula for Number of Billets per Die in [Cycle Time](#). The final cost for hard tooling takes into account the number of dies required for a production batch.

**Tool Total Cost =
Tool Hollow Die Adjusted Cost +
Tool Center Feed Cost +
Tool Shut Off Die Cost**

Total tool cost is the sum of the following:

- Tool hollow die adjusted cost: If the part has CrossSectionHollow GCDs, this is specified by the formula Tool Hollow Adjusted Die Cost. Otherwise, it is specified by the formula Tool Base Cost.
- Tool center feed cost: this is 0 if the part has 0 or 1 CrossSectionHollow GCDs. Otherwise, it is given by the formula Tool Center Feed Cost.
- Tool shut off die cost: this is 0 if the **Critical Tongue Ratio** is less than the tool shop variable **Shut Off Die Tongue Ratio Limit**. Otherwise, it is given by the formula Tool Center Feed Cost.

**Tool Hollow Die Adjusted Cost =
Tool Base Cost *
(Hollow Die Cost Multiplier +
(Multi-hollow Cost Multiplier * Number of Hollows))**

If the part has no CrossSectionHollow GCDs, tool hollow adjusted die cost is specified by the formula Tool Base Cost. Otherwise, it is specified by this formula, and depends on the following:

- Tool base cost: see formula.
- Hollow die cost multiplier: specified by the tool shop variable **Hollow Die Cost Multiplier**.
- Multi-hollow die cost multiplier: specified by the tool shop variable **Multi Hollow Die Cost Multiplier**.
- Number of hollows: this is the number of CrossSectionHollow GCDs that the part has.

Tool Center Feed Cost = Tool Hollow Adjusted Cost * Center Feed Cost Multiplier

Tool center feed cost is 0 if the part has 0 or 1 CrossSectionHollow GCDs. Otherwise, it is given by this formula, and is the product of the following:

- Tool hollow adjusted cost: this is 0 if the part has no CrossSectionHollow GCDs. Otherwise it is given by the formula Tool Hollow Die Adjusted Cost.
- Center feed cost multiplier: specified by the tool shop variable **Center Feed Cost Multiplier**.
- Tool Hollow Die Adjusted Cost =

**Tool Shut Off Die Cost =
Tool Base Cost * Shut Off Die Cost Multiplier**

Tool center feed cost is 0 if the part's **Critical Tongue Ratio** is less than the tool shop variable **Shut Off Die Tongue Ratio Limit**. Otherwise, it is given by this formula, and is the product of the following:

- Tool base cost: see formula.
- Shut off die cost multiplier: specified by the tool shop variable **Shut Off Die Cost Multiplier**.

**Tool Base Cost =
Tool Die Cost + Tool Bolster Cost + Tool Backer Cost + Tool Feeder Cost**

Tool base cost is the sum of the following:

-
- Tool die cost: if the part has at least one CrossSectionHollow GCD, this is specified by the formula Tool Hollow Die Cost. Otherwise, it is specified by the formula Tool Solid Die Cost. See the formulas below.
 - Tool bolster cost: the bolster supports additional pressure that the die cannot withstand. See formula.
 - Tool backer cost: the backer fills the non-bolster portion of the die stack, if necessary. The sum of the die and backer lengths is determined from a logarithmic function of billet diameter (specified by the machine property **Billet Diameter**), derived from a representative data sample. The backer is necessary only if this sum exceeds the Tool Die Thickness (see formula). See the formula for Tool Backer Cost, below.
 - Tool feeder cost: this value is 0 if no feeder is required, that is, if the **Outside Diameter** of the part's CrossSection is less than or equal to the machine's **Billet Diameter**. The feeder expands the flow of the billet to the parts that are outside of its diameter. If a feeder is required, tool feeder cost given by the formula Tool Feeder Cost, below.

**Tool Hollow Die Cost =
 (Hollow Die Cost Mass Coefficient * Tool Die Mass) +
 (Hollow Die Cost Nested Part Coefficient * Number of Die Cavities) +
 Hollow Die Cost Constant**

Tool hollow die cost depends on the following:

- Hollow die cost mass coefficient: specified by the tool shop variable **Hollow Die Mass Coeff.**
- Tool die mass: see formula.
- Hollow die cost nested part coefficient: specified by the tool shop variable **Hollow Die Cost Nested Part Coeff.**
- [Number of Die Cavities](#)
- Hollow die cost constant: specified by the tool shop variable **Hollow Die Constant.**

**Tool Solid Die Cost =
 (Solid Die Cost Mass Coefficient * Tool Die Mass) +
 (Solid Die Cost Nested Part Coefficient * Number of Die Cavities) +
 Solid Die Cost Constant**

Tool solid die cost depends on the following:

- Solid die cost mass coefficient: specified by the tool shop variable **Solid Die Mass Coeff.**
- Tool die mass: see formula.
- Solid die cost nested part coefficient: specified by the tool shop variable **Solid Die Cost Nested Part Coeff.**
- [Number of Die Cavities](#)
- Solid die cost constant: specified by the tool shop variable **Solid Die Constant.**

Tool Die Mass = Tool Material Density * Tool Die Volume

Tool die mass is the product of the following:

- Tool material density: specified by the tool shop variable **Tool Material Density**, converted from kg/m³ to kg/mm³ for use in this formula.
- Tool die volume: see formula.

Tool Die Volume = Tool Die Thickness * Tool Die Area

Tool die volume is the product of the following:

- Tool die thickness: this is the value given by the formula Tool Die Thickness (see below), rounded up to a standard thickness, and bounded above by Tool Die Max Thickness (see formula). Standard thicknesses are governed by the values in the lookup table **tblStandardSizes** for **extrusionToolLength** and the unit system specified by the cost model variable **defaultUnitSystem** (US in starting point VPEs).
- Tool die area: this is Pi times the square of half the Tool Diameter (see formula).

Tool Die Thickness = 2 * Critical Tongue Depth + Tool Pocket Thickness

Tool die thickness is the value given by this formula, rounded up to a standard thickness, and bounded above by Tool Die Max Thickness (see below). It depends on the following:

- **Critical Tongue Depth**
- Tool pocket thickness: depends on where the billet diameter (specified by the machine property **Diameter**) falls in the ranges specified by tool shop variables. Tool pocket thickness is specified by one of the following tool shop variables:
 - **Large Pocket Depth**, if Billet Diameter > **Large Pocket Depth Limit**
 - **Small Pocket Depth**, if Billet Diameter < **Small Pocket Depth Limit**
 - **Medium Pocket Depth**, otherwise

Tool Die Max Thickness

This value is determined from a logarithmic function of billet diameter (specified by the machine property **Billet Diameter**), derived from a representative data sample.

Tool Diameter = Billet Diameter * Die Diameter Adjustment Factor

Tool diameter is the value given by this formula, rounded up to a standard thickness. Standard thicknesses are governed by the values in the lookup table **tblStandardSizes** for **extrusionToolDiameter** and the unit system specified by the cost model variable **defaultUnitSystem** (US in starting point VPEs). Tool diameter is the product of the following:

- Billet diameter: specified by the machine property **Billet Diameter**.
- Die diameter adjustment factor: specified by the tool shop variable **Die Diameter Adjustment Factor**.

Tool Bolster Cost =

**(Bolster Cost Mass Coefficient * Tool Bolster Mass) +
(Bolster Cost Nested Part Coefficient * Number of Die Cavities) +
Bolster Cost Constant**

Tool bolster cost depends on the following:

- Bolster cost mass coefficient: specified by the tool shop variable **Bolster Cost Mass Coeff**.
- Tool bolster mass: see formula.

-
- Bolster cost nested part coefficient: specified by the tool shop variable **Bolster Cost Nested Part Coeff.**
 - **Number of Die Cavities**
 - Bolster cost constant: specified by the tool shop variable **Bolster Cost Constant.**

Tool Bolster Mass = Tool Material Density * Tool Bolster Volume

Tool bolster mass is the product of the following:

- Tool material density: specified by the tool shop variable **Tool Material Density**, converted from kg/m³ to kg/mm³ for use in this formula.
- Tool bolster volume: see formula.

Tool Bolster Volume = Tool Bolster Thickness * Tool Bolster Area

Tool bolster volume is the product of the following:

- Tool bolster thickness: this is the value given by the formula Tool Bolster Thickness (see below), rounded up to a standard thickness, and bounded below by 0. Standard thicknesses are governed by the values in the lookup table **tblStandardSizes** for **extrusionToolLength** and the unit system specified by the cost model variable **defaultUnitSystem** (US in starting point VPEs).
- Tool bolster area: this is Pi times the square of half the Tool Diameter (see formula).

Tool Bolster Thickness = Machine Stack Length – Required Die And Backer Length – Feeder Thickness

Tool bolster thickness is the value given by this formula, rounded up to a standard thickness, and bounded below by 0. It depends on the following:

- Machine stack length: specified by the machine property **Die Stack Length**.
- Required die and backer Length: this value is determined from a logarithmic function of billet diameter (specified by the machine property **Billet Diameter**), derived from a representative data sample.
- Feeder thickness: this value is 0 if no feeder is required, that is, if the **Outside Diameter** of the part's **CrossSection** is less than or equal to the machine's **Billet Diameter**.

Otherwise, this is the value given by the formula Feeder Thickness (see below), rounded up to a standard thickness. Standard thicknesses are governed by the values in the lookup table **tblStandardSizes** for **extrusionToolLength** and the unit system specified by the cost model variable **defaultUnitSystem** (US in starting point VPEs).

Feeder Thickness = (Tool Die Diameter – Billet Diameter) / tan(45)

Feeder thickness is determined based on the assumption that the feeder redirects flow at an angle of 45 degrees. It depends on the following:

- Tool die diameter: see formula.
- Billet diameter: specified by the machine property **Billet Diameter**.

Tool Backer Cost =

$$\text{Tool Backer Cost} = (\text{Backer Cost Mass Coefficient} * \text{Tool Backer Mass}) + (\text{Backer Cost Nested Part Coefficient} * \text{Number of Cavities In Die}) + \text{Backer Cost Constant}$$

The backer fills the non-bolster portion of the die stack, if necessary. The sum of the die and backer lengths is determined from a logarithmic function of billet diameter (specified by the machine property **Billet Diameter**), derived from a representative data sample. The backer is necessary only if this sum exceeds the Tool Die Thickness (see formula). If the backer is not necessary, tool backer cost is 0. Otherwise, tool backer cost depends on the following:

- Backer cost mass coefficient: specified by the tool shop variable **Backer Cost Mass Coeff.**
- Tool backer mass: see formula.
- Backer cost nested part coefficient: specified by the tool shop variable **Backer Cost Nested Part Coeff.**
- Number of cavities in die: see [Number of Die Cavities](#).
- Backer cost constant: specified by the tool shop variable **Backer Cost Constant**.

Tool Backer Mass = Tool Material Density * Tool Backer Volume

Tool backer mass is the product of the following:

- Tool material density: specified by the tool shop variable **Tool Material Density**, converted from kg/m³ to kg/mm³ for use in this formula.
- Tool backer volume: see formula.

Tool Backer Volume = Tool Backer Thickness * Tool Backer Area

Tool backer volume is the product of the following:

- Tool backer thickness: this is the value given by the formula Tool Backer Thickness (see below), rounded up to a standard thickness, and bounded below by 0. Standard thicknesses are governed by the values in the lookup table **tblStandardSizes** for **extrusionToolLength** and the unit system specified by the cost model variable **defaultUnitSystem** (US in starting point VPEs).
- Tool backer area: this is Pi times the square of half the Tool Diameter (see formula).

Tool Backer Thickness =

$$\text{Required Die And Backer Length} - \text{Tool Die Thickness}$$

Tool bolster thickness is the value given by this formula, rounded up to a standard thickness, and bounded below by 0. It depends on the following:

- Required die and backer Length: this value is determined from a logarithmic function of billet diameter (specified by the machine property **Billet Diameter**), derived from a representative data sample.
- Tool die thickness: this is the value given by the formula Tool Die Thickness (see formula), rounded up to a standard thickness, and bounded above by Tool Die Max Thickness (see formula). Standard thicknesses are governed by the values in the lookup table **tblStandardSizes** for **extrusionToolLength** and the unit system specified by the cost model variable **defaultUnitSystem** (US in starting point VPEs).

Tool Feeder Cost =

$$\text{Tool Feeder Cost} = (\text{Feeder Cost Mass Coefficient} * \text{Tool Feeder Mass}) + (\text{Feeder Cost Nested Part Coefficient} * \text{Number of Cavities In Die}) + \text{Feeder Cost Constant}$$

Tool feeder cost is 0 if no feeder is required, that is, if the **Outside Diameter** of the part's **CrossSection** is less than or equal to the machine's **Billet Diameter**. If a feeder is required, tool feeder cost given by this formula, and depends on the following:

- Feeder cost mass coefficient: specified by the tool shop variable **Feeder Cost Mass Coeff.**
- Tool feeder mass: see formula.
- Feeder cost nested part coefficient: specified by the tool shop variable **Feeder Cost Nested Part Coeff.**
- Number of cavities in die: see [Number of Die Cavities](#).
- Feeder cost constant: specified by the tool shop variable **Feeder Cost Constant**.

Tool Feeder Mass = Tool Material Density * Tool Feeder Volume

Tool feeder mass is the product of the following:

- Tool material density: specified by the tool shop variable **Tool Material Density**, converted from kg/m³ to kg/mm³ for use in this formula.
- Tool Feeder volume: see formula.

Tool Feeder Volume = Tool Feeder Thickness * Tool Feeder Area

Tool feeder volume is the product of the following:

- Tool feeder thickness: this is the values given by the formula **Feeder Thickness** (see formula, above), rounded up to a standard thickness. Standard thicknesses are governed by the values in the lookup table **tblStandardSizes** for **extrusionToolLength** and the unit system specified by the cost model variable **defaultUnitSystem** (US in starting point VPEs)..
- Tool feeder area: this is Pi times the square of half the Tool Diameter (see formula).

Billet Preheat

Process Time = Heating Time / Parts Per Billet

Process time depends on the following:

- Heating time: see formula. This value is converted from hours to seconds for use in this formula.
- Parts per billet: see [Billet Size and Parts per Billet](#).

Heating Time = Required Heat / Oven Power

Heating time in hours depends on the following:

- Required heat: see formula.
- Oven power: specified in kilowatts by the machine property **Machine Power**. This value is converted to watts for use in this formula.

Required Heat = (Billet Mass * Material Specific Heat at Room Temp * Delta Temp)

Required heat depends on the following:

- Billet mass: this is the product of billet volume and material density. See [Billet Size and Parts per Billet](#).
- Material specific heat at room temp: specified by the material property **Specific Heat RT**. This is the amount of heat energy per unit mass that is required to increase the material temperature one degree C.
- Delta temp: this is the magnitude of the temperature change effected by heating. See formula.

This value is converted from joules to watt-hours for use in the Heating Time formula.

Delta Temp = Solidus Temp – Room Temp

Delta temp is the magnitude of the temperature change effected by heating. It is the difference between the following:

- Solidus temp: specified by the material property **Solidus Temp**. This is the highest temperature at which the material remains in a solid state.
- Room temp: this is the ambient temperature, specified by the cost model variable **defaultRoomTemp** (23°C in starting point VPEs).

Die Preheat

Process Time = (Heating Time / Number of Dies) / Parts Per Die

Process time depends on the following:

- Heating time: see formula. This value is converted from hours to seconds for use in this formula.
- Number of dies: specified by the machine property **Number of Dies**.
- Parts per die: this is the number of parts produced by a die before it needs to be replaced. See formula.

Heating Time = Required Heat / Oven Power

Heating time in hours depends on the following:

- Required heat: see formula.
- Oven power: specified in kilowatts by the machine property **Machine Power**. This value is converted to watts for use in this formula.

Required Heat = (Billet Mass * Tool Material Specific Heat * Delta Temp)

Required heat depends on the following:

- Billet mass: this is the product of billet volume and material density. See [Billet Size and Parts per Billet](#).
- Tool material specific heat: specified by the Extrusion process tool shop variable **Tool Material Specific Heat**. This is the amount of heat energy per unit mass that is required to increase the temperature of the die material by one degree C.
- Delta temp: this is the magnitude of the temperature change effected by heating. See formula.

This value is converted from joules to watt-hours for use in the Heating Time formula.

Delta Temp = Solidus Temp – Room Temp

Delta temp is the magnitude of the temperature change effected by heating. It is the difference between the following:

- Solidus temp: specified by the part material property **Solidus Temp**. This is the highest temperature at which the part material remains entirely in a solid state.
- Room temp: this is the ambient temperature, specified by the cost model variable **defaultRoomTemp** (23°C in starting point VPEs).

Part per Die = Number of Billets per Die * Parts per Billet

The number of parts produced by a die (before it needs to be replaced) is the product of the following:

- Number of billets per die: this value is based on an evaluation of strain crack propagation. See the formula Number of Billets per Die in [Cycle Time](#).
- Parts per billet: see [Billet Size and Parts per Billet](#).

User Inputs

You can control the values listed below by modifying **Process Setup Options**, plant variables, or toolshop variables.

To access **Process Setup Options** for a given process, right click the process in the Manufacturing Process pane, and select **Process Setup Options** from the context menu.

See [Process Defaults and Thresholds](#) for more information on cost model variables.

The bar and tube process group provides the following process setup options:

- Bar & Tube Fabrication Node Options
- Extrusion Setup Options
- Other Setup Options

Bar & Tube Fabrication Node Options

The Bar & Tube Fabrication node provides the following setup options:

- Enable Scrap Material Credit
- Enable Scrap Part Credit
- Punching Strategy for Generic Extrusions

Enable Scrap Material Credit

By default in starting point VPEs, the cost model assumes that material scrap (for example, trim scrap) is *not* sold for credit. Administrators can customize the default with the cost model variable **enableScrapMaterialCredit** (**false** in starting point VPEs). With this setup option, users can override the default on a per-part basis.

Enabling scrap material credit increases material utilization and decreases material cost. The credit rate is specified as a percentage of the material rate by the material property **Scrap Cost Percent**. See [Material Cost and Utilization](#).

Enable Scrap Part Credit

By default in starting point VPEs, the cost model assumes that the material from scrapped parts is *not* sold for credit. Administrators can customize the default with the cost model variable **enableScrapPartCredit** (**false** in starting point VPEs). With this setup option, users can override the default on a per-part basis.

Enabling scrap part credit increases material utilization and decreases material cost. This includes credit for parts scrapped by this process as well as by downstream processes. The credit rate is specified as a percentage of the material rate by the material property **Scrap Cost Percent**. See [Material Cost and Utilization](#).

Punching Strategy for Generic Extrusions

By default, all a part's holes and cutouts are machined on a router (rather than punched), if any of the part's holes or cutouts lie on a fully-hollow **CrossSectionHollow** GCD. Users can override the default on a per-part basis with this setup option. The following options are provided:

-
- Option 1 (default): all a part's holes and cutouts are machined on a router (rather than punched), if any of the part's holes or cutouts lie on a fully-hollow CrossSectionHollow GCD.
 - Option 2: all a part's holes and cutouts are machined on a router (rather than punched), if any of the part's holes or cutouts lie on a fully-hollow or semi-hollow CrossSectionHollow GCD.
 - Option 3: some holes or cutouts may be machined while others are punched.
 - Option 4: all a part's holes and cutouts are machined on a router, regardless of whether any holes or cutouts lie on a CrossSectionHollow GCD.

Other Setup Options

For **Band Saw**, **Circular Saw**, and **Reciprocating Saw**, you can define the following process setup options:

- **Bundle Sawing**
 - **Compute bundle count:** uses a bundle count of 1.
 - **Override bundle count:** allows you to specify the bundle count (up to a maximum of 18).

For sawing processes, a bundle count greater than 1 allows the loading of multiple bars or tubes onto the saw machine to cut multiple stock pieces at once, which reduces cycle time.

For **Punching**, you can define the following process setup options:

- **Punch Heads**
 - **Use default number of heads:** uses a single punch head.
 - **Override number of heads:** allows you to specify the number of punch heads (which can decrease cycle time).

Punching machines can have more than one punch head to make multiple coaxial holes on a part, which decreases punching cycle time.

- **Mandrel Punching**
 - **Use Mandrel:** specifies the use of a mandrel (which can increase cycle time). The use of a mandrel for tube punching is a manufacturing option with which a die is inserted into the tube prior to and during fabrication. This prevents unwanted material.

For **Rotary Draw Bending**, you can define the following process setup options:

- **Bending**
 - **Mandrel Bending:** specifies the use of a mandrel (which can increase cycle time). The use of a mandrel for rotary draw bending is a manufacturing option with which a die is inserted into the tube prior to and during fabrication. This prevents unwanted material deformation and allows for tighter bending.

For **Roll Bending** (2-, 3-, or 4-roll) you can define the following process setup options:

- **Rolling speed** – The speed of the part through the machine, in mm/sec (or inches/sec).
- **Total part handling time** – Load time plus unload time (plus re-roll handling time if applicable), in seconds).

-
- Prebend time per edge – Not applicable for 2-roll machines. The time in seconds to pre-bend the leading or trailing edge. For 4-roll machines only, both leading and trailing edges can be pre-bent in one operation.
 - Number of passes – Not applicable for 2-roll machines. An integer specifying the number of passes required to generate the given bend.
 - Number of re-rolling passes -- Not applicable for 2-roll machines. The number of passes required after welding along the seam.

For **3-Roller Bending**, you can define the following process setup options:

Note: See the deprecation notice regarding this process at [Machines](#).

- **Handling Time**
 - **User override:** allows you to specify a value greater than or equal to zero.
 - **Default value:** uses default value.
- **Rolling Rate**
 - **Default value:** uses default value.
 - **User override:** allows you to specify a value greater than or equal to zero.
- **Number of passes**
 - **Default value:** uses default value.
 - **User override:** allows you to specify a value greater than or equal to zero.

When you use machining operations along with bar and tube processes, you can also define:

- **Tool Material Preference**
- **Virtual Tool Preference**
- **Setups**

Extrusion Setup Options

The Extrusion process provides the following setup options:

- Billet Length
- Number of Cavities in Die
- Ram Speed
- Quench Type
- Weld Scrap Included

Billet Length

By default, billet length is determined as described in [Billet Size and Parts per Billet](#). You can override the default with this setup option. Enter a standard length between the machine's **Min Billet Length** and **Max Billet Length**.

Standard lengths differ from one another by a multiple of the increment listed in the lookup table **tblStandardSizes** for **extrusionBilletLength** and the default unit system (specified by the cost model variable **defaultUnitSystem**—**US** in starting point VPEs).

Number of Cavities in Die

By default, the number of cavities in the die is the maximum number of cavities for which both the following hold:

- That number of cavities can fit on the die.
- That number of cavities results in an in-range exit speed.

The default number of cavities is the number arrived at in the calculation of [Maximum Acceptable Ram Speed](#). You can override the default with this setup option. Select one of the following options:

- **Optimized Based on Exit Speed:** this is the default. See [Maximum Acceptable Ram Speed](#).
- **Max Calculated:** this is the maximum number of cavities that can fit on the die—see [Maximum Number of Die Cavities](#).
- **User override:** enter a number of cavities between 1 and the value of the cost model variable `maxPossibleNestedPartsOnDie` (12 in starting point VPEs).

Note that if you override the default, the override does *not* affect [Machine Selection for Extrusion](#) or the calculation of [Maximum Acceptable Ram Speed](#). This value does drive [Hard Tooling Cost](#).

Ram Speed

By default, ram speed depends on a number of factors, including the following:

- Material properties **Minimum Extrusion Exit Speed** and **Maximum Extrusion Exit Speed**
- Part Complexity Reduction Factor
- Number of Die Cavities
- Quench Type
- Machine property **Max Ram Speed**

See [Maximum Acceptable Ram Speed](#) for more information.

You can override the default with this setup option. Select one of the following options:

- **Based on Part Complexity:** this is the default. See [Maximum Acceptable Ram Speed](#).
- **Machine Maximum Ram Speed:** this is the value of the machine property **Max Ram Speed**.
- **User Override:** enter a value in mm/sec between 0.01 and the value of the machine property **Max Ram Speed**.

Note that if you override the default, the override does *not* affect [Machine Selection for Extrusion](#). This value does drive [Cycle Time](#).

Quench Type

By default, the cost model assumes that the type of quenching is the most efficient type available for the selected machine. The quench types available for a given machine are specified by the following machine properties (those that are set to **true** are available):

- **Standing Wave** (most efficient)

-
- **Water Spray**
 - **Air** (least efficient)

You can override the default with this setup option.

Quench type affects the calculation of **Maximum Acceptable Ram Speed**, since ram speed must be slow enough to result in a balanced process. Longer quench times require slower ram speeds. **Maximum Acceptable Ram Speed**, in turn, affects **Machine Selection for Extrusion** as well as **Cycle Time**.

Weld Scrap Included

By default, **Billet Size and Parts per Billet** calculations assume that a region of un-usable weld scrap is produced when a billet that is loaded into the press fuses with the remainder of the previous billet. Set this setup option to **false** if you want to override the default and specify that such welded regions are *not* scrap and *are* usable in parts (for example, because neither structural nor aesthetic considerations prohibit using them).

Process Group Site Variables

Site variables in this process group control the following:

- Whether a bar with a hole is recognized as a tube. See [Tube Recognition](#).
- Whether some parts are recognized as generic extrusions. See [Extrusion Recognition](#).

To view or modify these site variables, click **Tools > VPE Toolset > Process Group Site Variables > Bar & Tube Fab**.

Tube Recognition

aPiori groups round stock into three ranges by the OD (outer diameter) -- thin, medium and thick.

Variables **maxThinRoundTubeOD** and **maxMediumRoundTubeOD** determine which group a particular stock is assigned to. Other variables determine whether the stock is a bar or a tube within the group.

- For the "thin" group, any ID (inner diameter) results in a tube.
- For the "medium" group, aPiori selects tube stock when:
 $ID \geq OD * \text{mediumRoundTubeMinIDFactor} - \text{mediumRoundTubeMinIDIntercept}$
- For the "thick" group, aPiori selects tube stock when:
 $(OD - ID) / 2 \leq \text{thickRoundTubeMaxWallThickness}$

where:

- **maxThinRoundTubeOD** (30.4mm by default) - Maximum OD for the "thin" group.
- **maxMediumRoundTubeOD** (141.3) - Maximum OD for the "medium" group.
- **mediumRoundTubeMinIDFactor** (0.8) - Coefficient in the medium group formula above.
- **mediumRoundTubeMinIDIntercept** (14) - Coefficient in the medium group formula above.

-
- **thickRoundTubeMaxWallThickness** (25.4) - Maximum thickness of a wall for a "thick" tube. Wall thickness is $(OD-ID)/2$. If wall thickness exceeds this value, the part is presumed to have been made from the bar stock. So if you have material that exceeds this value, which you want to process through roll-bending, you should increase the value of this site variable accordingly.

These site variables are ignored if you select round tube stock in the stock orientation tool.

Extrusion Recognition

Extrusions are recognized only if the site variable **enableGenericExtrusions** is set to **true**, the default in starting point VPEs. You can disable extrusion recognition by setting the variable to **false**.

Process Defaults and Thresholds

The table below lists some of the important plant variables, together with default values and descriptions.

Follow these steps to access plant variables for a given VPE and process:

- 1 Select **Tools > VPE Toolset**, and then click the **VPE Manager** button in the VPE Toolset window.
- 2 Double click the desired VPE in the Select VPE window.
- 3 In the VPE Manager, click + to expand the **Bar&Tube Fab** process group.
- 4 Under **Bar&Tube Fab**, click **Variables**.

Material Utilization

Variable Name	Where Used
enableScrapMaterialCredit	See Enable Scrap Material Credit .
enableScrapPartCredit	See Enable Scrap Part Credit .

Band Saw, Circular Saw, Reciprocating Saw

Variable Name	Where Used
Standard Stock Length	Material Calculations for virtual stock size
Min Leg Length	Trimming is added if at least one bend is within this distance from an End

Tube Laser

Variable Name	Where Used
Standard Stock Length	Material Calculations for virtual stock size
Thin to Thick Cut Threshold	Used to determine adjustments to the Tolerance Capability. Part is considered "Thick" if equal to or above this threshold
Thick Cut Tolerance Factor	Multiplier to adjust the tolerance capability if the part is considered to be thick according to the Thin to Thick Cut Threshold

Punching

Variable Name	Where Used
Thin to Thick Cut Threshold	Used to determine adjustments to the Tolerance Capability. Part is considered "Thick" if equal to or above this threshold

Thick Cut Tolerance Factor	Multiplier to adjust the tolerance capability if the part is considered to be thick according to the Thin to Thick Cut Threshold
----------------------------	--

Roll Bending

Variable Name	Where Used
#min2RollBendingDiameterRatio	Ratio which determines smallest achievable roll diameter as a function of the top roll diameter of machine (1.15)
referenceTensileStrength	Tensile strength at which single pass will switch to multipass for roll bending machine
rollingSpeedAdjustmentFactor	Adjustment ratio of speed when yield stress approaches 90% of the ultimate tensile stress
rollThicknessRatio	Ratio of part thickness as a function of machine capacity at which an additional pass should be added for rolling
standardSheetLength	Default standard sheet length if no stock is available for computed utilization.
standardSheetWidth	Default standard sheet width if no stock is available for computed utilization.
standardStockLength	Default length of stock. Used to set the standard length of material stock.

6 Casting--Die Process Group

This chapter describes the cost models and geometry extraction for gravity die casting and high-pressure die casting. Sand casting is covered in [Casting--Sand Process Group](#).

This chapter includes the following topics:

- Die Casting Cost Model Overview
 - GCD Extraction for Die Casting
 - Feasibility and Routing for Die Casting
 - Cost Algorithms and Calculations for Die Casting
 - User Inputs for Die Casting
 - Design-to-cost Configuration for Die Casting
-

Die Casting Cost Model Overview

This overview section summarizes assumptions and limitations of the following aspects of the model:

- Die Casting General Process
- Part Geometry for Die Casting
- Materials for Die Casting
- Machines for Die Casting
- Tooling for Die Casting

Die Casting General Process

In general, casting costs are determined by aggregating material, labor, machine, and tooling costs.

High-pressure die casting routings consist of the following processes:

- Melting
- High Pressure Die Casting
- Optional secondary processes

Gravity die casting routings consist of the following processes:

- Melting
- Coremaking (optional)
- Gravity Die Casting
- Trim
- Refractory Coat Cores
- Refractory Dry
- Cleaning
- Finishing
- Visual Inspection
- Optional secondary processes

If you have licensed the appropriate modules, your routing can include optional machining, heat treatment, and surface treatment processes, as well as testing, inspection, and packaging processes (which are part of the process group Other Secondary Processes).

See [Feasibility and Routing for Die Casting](#) for more information.

Part Geometry for Die Casting

Feasible geometries for die casting are limited by machine capabilities and by the selected VPE's minimum castable diameter for holes and voids.

A part is geometrically feasible for high-pressure die casting only if it satisfies the following requirements:

- Hole diameters and void box sizes are larger than 80 percent of the plant variable **minCastableHoleDia** for the selected VPE.
- Some machine that is included in the VPE satisfies the following requirements:
 - It is able to accommodate the horizontal and vertical dimensions of the mold base required for the part.
 - It is able to provide the clamp force required for the part. (The required clamp force is a function of the part's geometry as well as the material to be used.)

A part is geometrically feasible for gravity die casting only if the following holds:

- A machine that is included in the VPE can accommodate the horizontal and vertical dimensions of the mold base required for the part.

See [GCD Extraction for Die Casting, Machine Feasibility and Selection for Die Casting](#), and [Feasibility and Routing for Die Casting](#) for more information.

Materials for Die Casting

Supported materials include the following:

- Aluminum
- Aluminum Bronze
- Commercial Bronze
- Free-Cutting Brass
- Lead - cast
- Magnesium
- Manganese Bronze
- Silicon Brass
- Yellow Brass
- Zinc

See [Material Selection for Die Casting](#) for more information.

Machines for Die Casting

The following tables list important property value ranges of the machines supported for the central casting processes:

High Pressure Die Casting (Buhler, Frech, Idra, Profit, Quantum, and virtual machines)

Property	Low End	High End
Clamp Force (kN)	240	40,000
Max Mold Height (mm)	250	2100
Tie Bar Distance, Horizontal (mm)	250	2,100
Tie Bar Distance, Vertical (mm)	250	2100

Gravity Die Casting (Hall, IMBR, KURTZ, SIJIN, Zhenuan, and virtual machines)

Property	Low End	High End
Clamping Force (kN)	74.0	15,400.0
Max Mold Height (mm)	230	1845.0

Tie Bar Distance, Horizontal (mm)	450.0	1505.0
Tie Bar Distance, Vertical (mm)	405.0	1350.0

See [Machine Feasibility and Selection for Die Casting](#) for more information.

Tooling for Die Casting

High-pressure die casting molds can be machined out of Aluminum, H13 Tool Steel, or P20 Tool Steel. Users can specify the number of cavities, part maximum wall thickness (for cooling time calculations), and part tolerance, as well as several other tooling cost drivers.

Gravity casting molds can use 4140 Tool Steel or H13 Tool Steel. Users can specify the number of cavities, mold material, part tolerance, and maximum wall thickness, as well as several other tooling cost drivers.

Trim dies can use D2, A2, or S7 Tool Steel. Users can specify die material, among other tooling cost drivers.

The tooling model estimates the number of parts that can be produced with a given tool before it wears to the point that it needs to be replaced. Based on that estimate, the cost model determines the number of tools required to manufacture the production volume specified in the Production Scenario tab of the Cost Guide, and accounts for that number of tools in total hard tooling cost.

Tool-life estimation is based on part material, tool material, and tool coating type. For a given costing, either the formula Dependencies or Investment tab displays the number of tools assumed by tooling cost calculations.

See [Tooling Cost for Die Casting](#) and [User Inputs for Die Casting](#) for more information.

GCD Extraction for Die Casting

aPriori extracts the geometry of a CAD model in the form of geometric cost drivers (GCDs) that include Surfaces, Holes, Voids, and Combo Voids, as well as the Parting Line. As usual, there is a special GCD, Component, that represents the part as a whole.

Following are some of the important properties of each of these GCD types:

- **Component:**
 - Volume (mm³)
 - Surface Area (mm²)
 - Length, Width, and Height (millimeters)
 - Number of Surfaces
 - Min Thickness, Max Thickness, and Avg Thickness (millimeters)
 - Length Direction, Width Direction, and Height Direction: Each of these is a unit vector, two of whose components are 0 (the other component is 1 or -1). These vectors can be compared with the `Direction` vector of another GCD (such as a Perimeter or Setup Axis) in order to determine whether the GCD's direction is aligned with the part's length, width, or height.
- **Parting Line:**
 - Draw Direction
 - Height (millimeters)

- Parting Type
- Projected Area (mm²)
- **Surfaces (Curved Surface, Curved Wall, and Planar Face):**
 - Finished Area (mm²)
 - Bend Diameter (millimeters)
 - Perimeter (millimeters)
 - SER Length and SER Width (smallest enclosing rectangle dimensions in millimeters)
 - Corner Diameter (millimeters)
 - Inside Diameter (millimeters)
 - Number of Surfaces
 - Fillet Min Angle and Fillet Max Angle (degrees)
 - Round Radius (millimeters)
 - Round Length (millimeters)
- **Holes (Simple Hole, Multistep Hole):**
 - Diameter (millimeters),
 - Length and Depth (millimeters)
 - Volume (mm³)
 - Surface Area (mm²)
 - Maximum diameter and Minimum diameter (millimeters—for multistep holes)
 - Step count (for multistep holes)
 - Hole type (THROUGH or BLIND)
 - Blind, Sleeve Pin, Threaded, Countersunk, and Flanged (TRUE or FALSE)
 - Accessibility (THROUGH, OBSCURED, SIDE_A, SIDE_B, or UNDERCUT-- determines operation sequence and tooling requirements.)
- **Volumes (Void, Combo Void):**
 - Box Length, Box Width, Box Height (millimeters)
 - Exposed Area (mm²)
 - Number of Surfaces
 - Number of Openings
 - Perimeter (mm)
 - Surface Area (mm²)
 - Tool Reach (millimeters)
 - Volume (mm³)
 - Maximum Tool Diameter (millimeters)
 - Parting Line Draw Distance (millimeters)
 - Accessibility (THROUGH, OBSCURED, SIDE_A, SIDE_B, or UNDERCUT-- determines operation sequence and tooling requirements.)

The GCD extraction algorithm creates voids when it finds a probable core because a volume is inaccessible in the parting direction. Whenever a hole overlaps such a volume, a ComboVoid results.

Each ComboVoid consists of one or more holes and one or more voids. aPriori does not compute separate child GCDs for voids that are included in a ComboVoid, but it does compute GCDs for holes.

GCD extraction algorithms presume that holes that are children of ComboVoids are manufactured mostly by the casting processes. Any machining on these holes should be limited to surface finishing operations. If aPriori models a drilling operation for such a hole, the drill should go faster as it would mostly go through air and contact metal only on the edges.

The unmerging user action signals to aPriori that the hole that was presumed to be cast, needs to be machined (right-click the ComboVoid and select **Unmerge**). Specifically this means that the GCD extraction algorithm fills in these holes before computing thicknesses.

For High Pressure Die Casting, inaccessible holes, voids, and combo voids that are obscured or undercut are assumed to be machined. You must unmerge any such combo voids, so that the constituent holes and voids can be assigned machining operations. Such combo voids that are not unmerged will fail to cost.

The GCD extraction algorithm also fills in *uncastable* holes before computing thickness, based on two site variables, **minCastableHoleDiameter** and **minCastableHoleWallThickness**. Uncastable holes are those whose diameter is below **minCastableHoleDiameter** and those whose wall thickness is below **minCastableHoleWallThickness**. Uncastable holes are never included in ComboVoids. Note that VPEs may have variables with the same name as the site variables. The VPE variables change the cost model behavior but have no effect on GCD extraction.

In some rare cases the algorithm that fills in holes fails. In this case aPriori does not create a hole GCD at all.

Slide Bundles for Die casting

aPriori analyzes a part's holes and voids in order to determine which, if any, must be handled by a side core or slide. For those GCDs that require a slide, aPriori determines which can be grouped together onto a common action. In this way, aPriori can determine the number and sizes of the slides required for the part's mold.

Each resulting slide is represented by a GCD with a name such as **SlideBundle:1** or **SlideBundle:2**, and so forth. These GCDs appear in the Geometric Cost Drivers pane under the **Slide Bundles**, which appear under the **Volume** node.

You can override the bundling analysis, and specify the number of small, medium, and large bundles with process setup options. See [User Inputs for Die Casting](#).

Feasibility and Routing for Die Casting

When you choose the Casting process group, aPriori selects process-level routings, operation-level routings, as well as machines and materials. These procedures are described in the following sections:

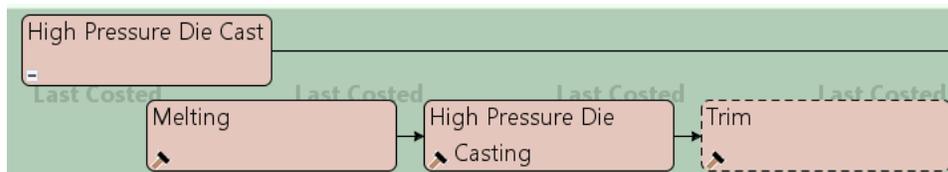
- [Die Casting Process-level Routing](#)
- [High Pressure Die Casting Operation-level Feasibility](#)
- [Gravity Die Casting Operation-level Feasibility](#)

- Material Selection for Die Casting
- Machine Feasibility and Selection for Die Casting

Die Casting Process-level Routing

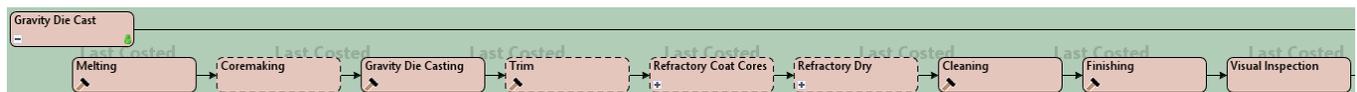
High-pressure die casting routings consist of the following processes:

- Melting
- High Pressure Die Casting
- Trim
- Optional secondary processes

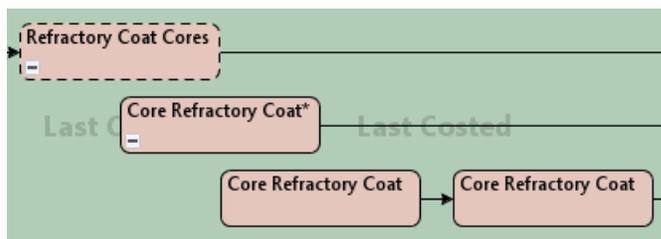


Gravity die casting routings are never auto-selected. You must manually select gravity die casting routings. They consist of the following processes:

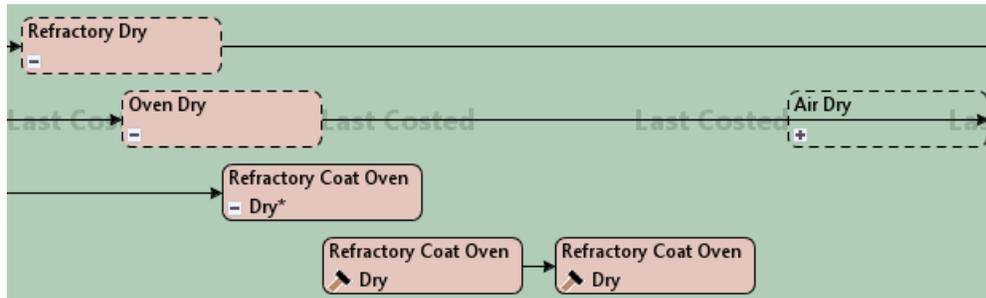
- Melting
- Coremaking (optional)
- Gravity Die Casting
- Trim
- Refractory Coat Cores
- Refractory Dry
- Cleaning
- Finishing
- Visual Inspection
- Optional secondary processes



By default in starting point VPEs, refractory coating and drying are assumed to be applied to any sand cores. (Refractory coating is also known as "foundry coating", "protective coating", "wash", and "blacking".) There can be multiple instances of a core coating process in order to model the application of multiple coats. See [Core Refractory Coating for Die Casting](#) for more information.



Coated cores are oven dried by default, if they can fit in an oven; otherwise they are air dried. There can be multiple instances of a drying process in order to model drying after each of multiple coats. See [Refractory Coat Oven Dry for Die Casting](#) and [Refractory Coat Air Dry for Die Casting](#).



Users can manually exclude individual cores from being coated, and can also include air drying instead of oven drying, on per-GCD basis. See [Refractory Coating Setup Options for Sand Casting](#) for more information.

If you have licensed the Machining process group, your routing can include any of the following secondary processes:

- 3-Axis Milling
- Cylindrical Grinding
- Gun Drill
- 2-axis Wire EDM operations
- Single Index Milling and Rotor Grinding operations (if helical groove geometry is present)

If you have licensed the optional Turning module, your routing can include the turning processes using the following lathe types:

- 2-axis
- 3-axis,
- 4-axis
- 6-axis

Note that if you select **This part is not machined** in the Production Scenario tab of the Cost Guide, but then manually select any GCD operation sequences which require machining, the corresponding GCDs will fail to cost with the message **User-selected operations are unavailable in the current routing**.

Your routing can also include processes from the following process groups, if you have licensed these modules:

- Heat Treatment
- Surface Treatment
- Other Secondary Processes, including packaging, Xray inspection, and various types of testing.

High Pressure Die Casting Operation-level Feasibility

Below are the Die Casting operations that have associated feasibility rules, grouped by GCD type. Each operation is accompanied by necessary conditions for the operation's

feasibility. aPriori checks the operations in the order specified by the operation templates.

Note: inaccessible holes, voids, and combo voids that are obscured or undercut are assumed to be machined. You must unmerge any such combo voids, so that the constituent hole and void can be assigned machining operations. Such combo voids that are not unmerged will fail to cost (see also [GCD Extraction for Die Casting](#)).

See [Trim Machine Selection](#) for information on Trim operation feasibility, which affects tooling cost as well as required clamp force.

Curved Surface

- *As Cast*
 - Surface area is nonzero.
 - Tolerance is not too small to cast, if secondary machining is disabled.
 - GCD does not lie on an axigroove.

Curved Wall

- *As Cast*
 - Surface area is nonzero.
 - Tolerance is not too small to cast, if secondary machining is disabled.
 - GCD does not lie on an axigroove.

Void and ComboVoid

- *All Operations*
 - Box width is not too small to cast (that is, diameter is greater than or equal to the plant variable `minDieCastableHoleDia`).
 - Box height is not too small to cast (that is, diameter is greater than or equal to the plant variable `minDieCastableHoleDia`).
- *Insert Coring*
 - GCD is obscured or undercut.
 - GCD is not accessible from the draw direction.
- *Side Coring*
 - GCD is obscured or undercut.
 - GCD is accessible from the void direction.
- *No Coring*
 - GCD is accessible from the draw direction (accessibility is Side A, Side B, or Through).

Multistep Hole

- *All Operations*
 - Diameter is not too small to cast (that is, diameter is greater than or equal to the plant variable `minDieCastableHoleDia`).
- *Insert Coring*
 - Always infeasible
- *No Coring*
 - Hole is accessible from the draw direction (accessibility is Side A, Side B, or Through)
 - Hole is not threaded, if secondary machining is disabled.

- *Side Coring*
 - Hole is obscured from the draw direction.
 - Hole has unobstructed parallel access for a slide.
- *Hole Unscrewing*
 - The GCD is threaded.

Planar Face

- *As Cast*
 - Surface area is nonzero.
 - Tolerance is not too tight to cast, if machining is disabled.

Simple Hole

- *All operations*
 - Diameter is not too small to cast (that is, diameter is greater than or equal to the plant variable `minDieCastableHoleDia`).
 - Tolerance is not too tight to cast, if secondary machining is disabled.
- *Insert Coring*
 - Always infeasible
- *No Coring*
 - Hole is accessible from the draw direction (accessibility is Side A, Side B, or Through)
 - Hole is not threaded, if secondary machining is disabled.
- *Side Coring*
 - Hole is obscured from the draw direction.
 - Hole has unobstructed parallel access for a slide.
- *Hole Unscrewing*
 - The GCD is threaded.

Gravity Die Casting Operation-level Feasibility

Below are the PM operations that have associated feasibility rules, grouped by GCD type. Each operation is accompanied by necessary conditions for the operation's feasibility. aPriori checks the operations in the order specified by the operation templates.

See [Trim Machine Selection](#) for information on Trim operation feasibility, which affects tooling cost as well as required clamp force.

Curved Surface

- *As Cast*
 - Surface area is nonzero.
 - Tolerance is not too small to cast, if secondary machining is disabled.
 - GCD does not lie on an axigroove.

Curved Wall

- *As cast*
 - Surface area is nonzero.
 - Tolerance is not too small to cast, if secondary machining is disabled.

- GCD does not lie on an axigroove.

Void and ComboVoid

- *All Operations*
 - Box width is not too small to cast (that is, diameter is greater than or equal to the plant variable **minDieCastableHoleDia**).
 - Box height is not too small to cast (that is, diameter is greater than or equal to the plant variable **minDieCastableHoleDia**).
- *Side Pull*
 - GCD is obscured or undercut.
 - GCD is not accessible from the draw direction.
- *No Side Pull*
 - GCD is accessible from the draw direction (accessibility is Side A, Side B, or Through).

Multistep Hole

- *All operations*
 - Diameter is not too small to cast (that is, diameter is greater or equal to than the plant variable **minPermanentMoldHoleDia**).
 - Tolerance is not too tight to cast, if secondary machining is disabled.
 - Hole is not threaded, if secondary machining is disabled.
- *No Side Pull*
 - Hole is accessible (accessibility is Side A, Side B, or Through)
- *Side Pull*
 - Hole is obscured.
 - Hole has unobstructed parallel access for a slide.

Planar Face

- *As Cast*
 - Surface area is nonzero.
 - Tolerance is not too small to cast, if secondary machining is disabled.

Simple Hole

- *All operations*
 - Diameter is not too small to cast (that is, diameter is greater or equal to than the plant variable **minPermanentMoldHoleDia**).
 - Tolerance is not too tight to cast, if secondary machining is disabled.
 - Hole is not threaded, if secondary machining is disabled.
- *No Side Pull*
 - Hole is accessible (accessibility is Side A, Side B, or Through)
- *Side Pull*
 - Hole is obscured.
 - Hole has unobstructed parallel access for a slide.

Material Selection for Die Casting

In direct integration mode with Pro/ENGINEER, if the composition selection mode is **MCAD**, aPriori selects the MCAD composition from the part, if available. Otherwise aPriori selects the VPE default material (Aluminum AL380 for all starting point VPEs).

In CAD-independent mode, aPriori selects the VPE default material (Aluminum AL380 for all starting point VPEs).

In both direct integration and CAD-independent mode, you can either use aPriori's selection or else manually select a material composition and override the material unit cost. To manually specify a material, select **Edit > Material Selection** in the Manufacturing Process pane (see also [Selecting material in Manufacturing Process Information](#)).

Machine Feasibility and Selection for Die Casting

This section contains the following subsections:

- [Melting Machine Selection](#)
- [Molding Machine Selection](#)
- [Cleaning Machine Selection](#)
- [Coremaking Machine Selection](#)
- [Refractory Coat Oven Dry Machine Selection](#)

Melting Machine Selection

If aPriori is configured to automatically select a Melting machine (that is, a furnace), it selects the machine with the lowest machine overhead rate that satisfies all the feasibility rules. If two feasible machines have the same machine overhead rate, aPriori selects the one with the smallest capacity.

aPriori selects only from preferred machines, if there is a feasible preferred machine and the cost model variable **usePreferredMachines** is set to **true** (the default in starting point VPEs). If there is no feasible preferred machine, or if the cost model variable **usePreferredMachines** is set to **false**, aPriori selects from all machines. A machine is preferred if the machine property **isPreferred** (typically displayed as **Is Preferred**) is **true**.

The feasibility rules require that the furnace have a sufficient capacity and maximum temperature. More specifically, a machine is feasible only if both the following are true:

- The furnace's maximum temperature is not less than the material's injection temperature:
 - Furnace maximum temperature: specified by the machine property **Max Temperature**.
 - Material injection temperature: specified by the material property **Injection Temp**.
- The furnace's capacity is sufficiently greater than the per-part pouring volume. In starting point VPEs, furnace capacity must exceed pouring volume by a factor of 1.5:
 - Furnace capacity: specified by the machine property **Furnace Capacity**.
 - Per-part pouring volume: depends on material density and pouring mass. Pouring mass is Mass Before Machining + Mass Waste + Mass Bad Parts + Mass Loss. See the formulas in [Material Cost and Utilization for Die Casting](#).

- Safety factor: specified by the cost model variable **furnaceCapacitySafetyFactor** (1.5 in starting point VPEs). Furnace capacity must be greater than or equal to the product of the pouring volume and the safety factor.

To manually select a machine for a given process, select **Edit > Routing Selection** in the Manufacturing Process pane, right-click on the process in the Routing Selection window, and select **Machine Selection** from the context menu (see also [Selecting a machine for an operation in Manufacturing Process Information](#)).

Molding Machine Selection

If aPriori is configured to automatically select a molding machine, it selects the machine with the lowest machine overhead rate (Gravity Die Casting) or clamp force (High Pressure Die Casting) that satisfies all the feasibility rules.

aPriori selects only from preferred machines, if there is a feasible preferred machine and the cost model variable **usePreferredMachines** is set to **true** (the default in starting point VPEs). If there is no feasible preferred machine, or if the cost model variable **usePreferredMachines** is set to **false**, aPriori selects from all machines. A machine is preferred if the machine property **isPreferred** (typically displayed as **Is Preferred**) is **true**.

The feasibility rules require that the mold required for the part can fit on the machine, and (for High Pressure Die Casting) that the machine has sufficient press force. More specifically, a machine is feasible only if all the following are true:

- High Pressure Die Casting:
 - Machine clamp force is greater than or equal to the required force.
 - Horizontal machine tie bar distance is greater than or equal the horizontal dimension of the mold base.
 - Vertical machine tie bar distance is greater than or equal to the vertical dimension of the mold base.
- Gravity Die Casting:
 - Horizontal machine tie bar distance is greater than or equal the horizontal dimension of the mold base.
 - Vertical machine tie bar distance is greater than or equal to the vertical dimension of the mold base.
 - Machine maximum mold height is greater than or equal to the mold base height.

aPriori calculates the mold dimensions and clamp force required for a given part based on a number of factors, including the minimum required number of cavities in the mold. If you don't use the PSO **Number of Cavities** (see [User Inputs for Die Casting](#)), the minimum required number of cavities is specified by the cost model variable **defulatNumCavities** or **defulatNumCavitiesGravityDieCasting** (1 in the starting point VPEs), so aPriori finds a machine that can accommodate at least a single-cavity mold.

By using the PSO, you can specify the number of cavities explicitly or specify that aPriori use the number of cavities required to meet the annual production volume. You can also use the PSO to specify that aPriori should use the combination of machine and number of cavities that results in the lowest per part cost. Calculation of clamp force is described in [Required Clamp Force](#). Calculation of the number of cavities assumed for cost estimates is described in [Number of Mold Cavities for Die Casting](#).

To manually select a machine for a given process, select **Edit > Routing Selection** in the Manufacturing Process pane, right-click on the process in the Routing Selection window,

and select **Machine Selection** from the context menu (see also Selecting a machine for an operation in Manufacturing Process Information).

Cleaning Machine Selection

There are three types of cleaning machines, all of which use shot blast:

- **Tumble Blast:** Uses wheel blasting. Parts are moved by a conveyor belt, causing them to tumble, exposing all surfaces to the shot stream.
- **Table Blast:** Uses wheel blasting. One or more parts are placed on a table which rotates, exposing them to the shot stream. The cost model assumes that parts are turned over or re-positioned by hand during a pause in blasting. The machine property **timePerLoad** is the the total blast time, and does not include reorient time.
- **Room Blast:** For very large parts. Uses air blasting. In a cleaning room, an operator manually directs shot at the part, or a robot programmatically directs shot at the part. The cost model assumes that the parts are reoriented during a pause in blasting.

The machine type is specified by the machine property **Type**.

aPiori selects the smallest machine (by weight capacity) that is feasible for the current part (see below). aPiori selects only from preferred machines, if there is a feasible preferred machine and the cost model variable **usePreferredMachines** is set to **true** (the default in starting point VPEs). If there is no feasible preferred machine, or if the cost model variable **usePreferredMachines** is set to **false**, aPiori selects from all machines. A machine is preferred if the machine property **isPreferred** (typically displayed as **Is Preferred**) is **true**.

A machine is feasible if it can accommodate all the following:

- Weight of a load with at least the minimum number of parts required for an economic load.
- Height of the part.
- Length or width of the part, whichever is smaller
- Volume (for Tumble Blast) or area (for Table Blast) of a load with at least the minimum number of parts required for an economic load.

The minimum number of parts in an economic load is specified by the machine property **Min Number Parts**. This is an estimate of the minimum number of parts that would make the machine worth using instead of a smaller machine.

Trim Machine Selection

If aPiori is configured to automatically select a trim machine, it selects the machine with the lowest machine overhead rate that satisfies all the feasibility rules.

aPiori selects only from preferred machines, if there is a feasible preferred machine and the cost model variable **usePreferredMachines** is set to **true** (the default in starting point VPEs). If there is no feasible preferred machine, or if the cost model variable **usePreferredMachines** is set to **false**, aPiori selects from all machines. A machine is preferred if the machine property **isPreferred** (typically displayed as **Is Preferred**) is **true**.

The feasibility rules require that the trim mold required for the part can fit on the machine, and that the machine has sufficient clamp force. More specifically, a machine is feasible only if all the following are true:

- Machine clamp force is greater than or equal to the required force, where
 - Machine clamp force is specified by the machine property **Press Force**.
 - Required clamp force is the product of material shear strength and total trim area. Trim area is the area covered by removed material. Removed material is assumed to run along the parting line, as well as the surfaces of holes and voids for which trimming is feasible (see below).
- Mold height plus bottom parallel height is no greater than the machine shut height, where
 - Mold height is calculated based on a number of factors, some which are affected by Trim setup options. See Part Height Allowance, [Minimum Part Height Plus Allowance](#), and [Post Height Multiplier](#) for more information.
 - Bottom parallel height is specified by the cost model variable **bottomParallelHeight** (101.6mm in starting point VPEs).
 - Machine shut height is specified by the machine property **Installation Height**.

Trimming is feasible for those holes and voids that meet the following requirements:

- Hole is known not be obscured, undercut, or blind.
- Hole diameter is no less than the cost model variable **minTrimHoleDiameter** (25.4mm in starting point VPEs). Note that for threaded holes, hole diameter is the diameter *prior to threading*, that is, final hole diameter minus twice the value of the cost model variable **finishAllowance** (0.25mm in starting point VPEs).
- Hole's diameter to length ratio is no less than the cost model variable **trimDiaToDepthRatio** (0.5 in starting point VPEs).
- Hole does not require secondary operations to achieve required tolerance.
- Hole is not a complex hole. (Trimming of complex holes is not supported in this release.)

To manually select a machine for a given process, select **Edit > Routing Selection** in the Manufacturing Process pane, right-click on the process in the Routing Selection window, and select **Machine Selection** from the context menu (see also [Selecting a machine for an operation in Manufacturing Process Information](#)).

Coremaking Machine Selection

For Coremaking, aPriori selects the machine with the smallest corebox capacity that meets the following requirements:

- Machine can accommodate a corebox with at least one cavity for the part's largest hole or void. Note that the machine must be able to accommodate the largest hole or void, regardless of whether aPriori determines that the hole or void requires a core, since any hole or void could potentially be *manually* assigned a coring operation.
- Current scenario's annual production volume falls within the machine's **minAnnualVol** and **maxAnnualVol** limits (if limits are set).

A machine's corebox capacity is given by the machine properties **Max Corebox Length**, **Max Corebox Width**, and **Max Corebox Height**. A machine can accommodate a GCD if these dimensions equal or exceed the dimensions of the corebox required for the GCD. The dimensions of the required corebox are the dimensions of the GCD's smallest enclosing box, extended to account for coreprints (extensions of sand for hanging the core in the

mold), and supplemented by the corebox wall thickness (specified by the cost model variable **coreboxLengthAllowance**--19mm in starting point VPEs).

The GCD properties **Dir CorePrints Box Length**, **Dir Core Prints Box Width**, and **Dir Core Prints Box Height** indicate which dimensions should be extended, and whether the dimension should be extended in one or both directions. For example, if **Dir Core Prints Box Length** is 0, this indicates that an extension along the length dimension is *not* required (because both directions are blocked by the part); if **Dir Core Prints Box Length** is 1, this indicates that the length should be extended in one direction to account for coreprints (because the other direction is blocked by the part); if **Dir Core Prints Box Length** is 2, this indicates that the length should be extended in both directions to account for coreprints (because neither direction is blocked).

The cost model variable **lengthCorePrint** (10mm in starting point VPEs) indicates the extension length in each direction. So, for example, if **Dir Core Prints Box Length** is 2, the GCD's box length dimension is extended by 10mm in each direction (20mm total), in starting point VPEs.

Refractory Coat Oven Dry Machine Selection

Machine selection for Refractory Coat Oven Dry picks the lowest-volume feasible machine. A machine is feasible if it can accommodate, individually, each of the part's oven-dryable cores.

A core is oven-dryable if it can fit in the *largest* available oven. Cores that are too large for any available oven are air dried.

Note that the cost model assumes the use of a single oven for a given part, that is, the cost model assumes that the same oven is used for all the part's oven-dried cores.

Machine volume is the product of the machine properties **Bed Length**, **Bed Width**, and **Bed Height**.

In starting point VPEs, which assume a spacing factor of 0.8, an oven can accommodate a core (or, equivalently, a core can fit in an oven) if all the following hold:

- Longest dimension of the bounding box of the core is no greater than 80% if the machine **Bed Length**.
- Shortest dimension of the bounding box of the core is no greater than 80% if the machine **Bed Height**.
- Intermediate dimension of the bounding box of the core is no greater than 80% if the machine **Bed Width**.

Administrators can configure the spacing factor with the cost model variable **defaultRefractoryCoatOvenSpaceAvailableFactor** (0.8 in starting point VPEs).

See also [Core Bounding Box Dimensions](#).

Cost Algorithms and Calculations for Die Casting

If machining processes are included as secondary processes on Casting components, then the machining costs are computed via the Machining cost model and combined with the casting process costs to produce a total manufacturing process cost.

Total casting costs aggregate the costs of material, labor, equipment, and tooling. Typically, tooling accounts for a significant portion of the total cost. The part's wall thickness and material (because they affect cooling time) have a significant impact on both labor and tooling costs.

This section details how costs are calculated by aPriori. Note that you can override the calculation of many of the quantities involved, and specify them explicitly—see [User Inputs for Die Casting](#), below.

When not otherwise specified, costs are per part.

This section covers formulas in the following areas:

- [Yields For Die Casting](#)
- [Material Cost and Utilization for Die Casting](#)
- [Labor and Setup Costs for Die Casting](#)
- [Gating System Model for Die Casting](#)
- [Melting Formulas for Die Casting](#)
- [Cleaning Formulas for Die Casting](#)
- [Finishing Formulas for Die Casting](#)
- [Visual Inspection Formulas for Die Casting](#)
- [Design Complexity Factor](#)
- [High Pressure Die Casting and Gravity Die Casting Process Formulas](#)
- [Trim Formulas for Die Casting](#)
- [Core Refractory Coating for Die Casting](#)
- [Refractory Coat Oven Dry for Die Casting](#)
- [Refractory Coat Air Dry for Die Casting](#)
- [Required Clamp Force](#)
- [Coremaking for Die Casting](#)
- [Number of Mold Cavities for Die Casting](#)
- [Tooling Cost for Die Casting](#)

Yields For Die Casting

This section describes how yields are calculated for all Casting processes.

Final Yield = Final Output Volume / Input Volume

Final yield affects labor and overhead costs per part (it does not affect material cost—but see [Non-foundry Yield in Material Cost and Utilization for Die Casting](#)). It is the fraction of the total number of parts created by this process in the current production scenario that will survive as good parts once any secondary processes are completed. That is, final yield is the fraction of parts created by this process that are *not* discarded as scrap

parts, either by this process or by a downstream process. Final yield depends on the following:

- Final output volume (product of the annual volume and number of production years, specified in the Production Scenario screen of the Cost Guide)
- Input volume (see the formula below). This is the total number of parts produced by this process, including all parts discarded as scrap from this process or downstream processes.

Input Volume = Local Output Volume + Number of Scrap Parts for This Process

Input volume is the total number of parts produced by this process in the current scenario, including all parts discarded as scrap from this process or downstream processes. It is the sum of the following:

- Local output volume (see the formula below). This is the number of parts produced by this process, excluding parts discarded as scrap by this process, but including parts that are discarded as scrap by downstream processes.
- Number of scrap parts for this process (see the formula below)

Local Output Volume = Final Output Volume + Number of Scrap Parts Downstream

Local output volume is the number of parts produced by this process in the current scenario, excluding parts discarded as scrap by this process, but including parts that are discarded as scrap by downstream processes. It is the sum of the following:

- Final output volume (product of volume and number of production years, specified in the Production Scenario screen of the Cost Guide)
- Number of Scrap Parts Downstream. This is the number of parts discarded as scrap by downstream processes.

Number of Scrap Parts for This Process = (Local Output Volume / Good Part Yield) – Local Output Volume

Number of scrap parts for this process is the number of parts produced by this process in the current scenario that are discarded as scrap by this process, before any downstream process is performed on them. It is a function of the following:

- Local output volume (see the formula above)
- Good part yield (specified by the machine property **Good Part Yield**). This is the fraction of parts produced by this process that are not discarded as scrap by this process but may be discarded as scrap by downstream processes.

Material Cost and Utilization for Die Casting

This section describes how material cost and utilization are calculated for the Casting utilization process, Melting.

Material Cost = Rough Mass * Material Unit Cost

Material cost is the product of the following:

- Rough Mass (see formula)
- Material unit cost (specified by the material property **Cost**)

Rough Mass = Finish Mass / Utilization

Rough mass is the mass per part that accounts for material cost per part. In the default utilization mode, it is the sum of the following:

- Mass of the finished part
- Mass of the metal chips removed from the part by secondary machining operations
- Mass of the un-remeltable material lost per part due to spillage and oxidation
- Mass of the material lost due to parts scrapped by non-foundry processes (amortized over all parts in the current production scenario)

This assumes the following can be remelted, and so does not contribute to material cost:

- Parts scrapped by processes performed at the foundry
- Contents of the feeder system (runners, risers, etc.)

In all utilization modes, rough mass depends on the following:

- Finish mass (product of part volume and material density)
- Utilization (specified by the formula below, or specified in the Material Utilization section of the Material Selection dialog)

Utilization = Part Volume / ((Part Volume + Metal Chip Volume + Volume Loss + Non-remeltable Volume) / Non-foundry Yield)

In the default utilization mode, utilization depends on the following:

- Part volume (determined by geometry extraction)
- Metal chip volume: derived by summing metal chip volume for each machining operation that is applied to the part. For fully-machined features, this calculation is based on feature volume. For machine-finished features, the calculation is based on the area of the finished surface. The calculation assumes that the depth of material removed during finishing is the value specified by the cost model variable **finishAllowance**.
- Volume loss (see formula)
- Non-remeltable volume (see formula)
- Non-foundry yield (see formula)

Volume Loss = Mass Loss / Material Density

Volume loss is the pouring volume of metal that is oxidized or spilled during melting and cannot be re-melted. It is a function of the following:

- Mass loss. Specified by the formula below or the process setup option Mass Loss—see [User Inputs for Die Casting](#).
- Material density (specified by a material property)

Mass Loss = Mass Poured Excluding Loss * (1 / (Machine Yield Loss * Material Yield Loss Factor) - 1)

Mass loss is the pouring mass of metal that is oxidized or spilled during melting and cannot be remelted. By default, it is specified by this formula. Users can override the default with the process setup option Mass Loss—see [User Inputs for Die Casting](#). Computed mass loss is a function of the following:

- Mass poured excluding loss. See formula below.

- Machine yield loss: fraction of material not lost through spillage (specified by a machine property)
- Material yield loss factor: fraction of material not lost through oxidation (specified as a material property)

Mass Poured Excluding Loss = Mass Before Machining + Mass Waste

This is the portion of the mass poured per part that includes remeltable material from runners and risers, as well as material from scrapped parts (amortized over all the parts in the current production scenario), but does not include mass lost due to spillage and oxidation. It is the sum of the following:

- Mass before machining (see formula)
- Mass waste. Specified by the user with the process setup option Mass Waste (see [User Inputs for Die Casting](#)) or calculated with the formula below.

Mass Before Machining = (Part Volume + Metal Chip Volume of Machined Features) * Material Density

Mass before machining is the part mass plus the mass removed by machining. It depends on the following:

- Part volume (obtained from GCD extraction)
- Metal chip volume of machined features: derived by summing metal chip volume for each machining operation that is applied to the part. For fully-machined features, this calculation is based on feature volume. For machine-finished features, the calculation is based on the area of the finished surface. The calculation assumes that the depth of material removed during finishing is the value specified by the cost model variable **finishAllowance**.
- Material density (specified by a material property)

Mass Waste = Total Gating Mass / Number of Cavities

Mass waste is the mass per cavity of that portion of the pouring volume contained in the feeder system (runners, risers, etc.). By default, it is specified by this formula. Users can override the default with the process setup option Mass Waste—see [Melting Process Inputs](#). Computed mass waste is a function of the following:

- Total gating mass is the mass of that portion of the pouring volume contained in the entire feeder system. It is the product of material density and total gating volume--see Total Gating Volume in [Gating System Formulas for High Pressure Die Casting](#) or [Gating System Formulas for Gravity Die Casting](#).
- Number of cavities (see [Number of Mold Cavities for Die Casting](#))

Non-remeltable Volume = Volume Waste * (1 – Remelt Allowance)

Non-remeltable volume depends on the following:

- Volume Waste: this is Mass Waste (see formula) divided by material density.
- Remelt Allowance: the default remelt allowance is specified by the cost model variable **defaultRemeltAllowancePM** (1 in starting point VPEs). Users can override the default with the setup option Material Remelt Allowance Percentage.

Non-foundry Yield = Final Output Volume / (Final Output Volume + Non-foundry Scrap Parts)

Non-foundry yield affects material cost per part. It is the fraction of parts created by this process in the current production scenario that will either survive as good parts once any secondary processes are completed or will be scrapped and remelted. That is, non-foundry yield is the fraction of parts created by this process that are *not* discarded as un-remeltable scrap parts by a downstream process.

Note that scrap parts from downstream, secondary (non-foundry) processes are assumed to be un-remeltable; parts scrapped by foundry processes are assumed to be remelted. The presence of the node attribute **inFoundryProcess** indicates a foundry process.

Non-foundry yield depends on the following:

- Final output volume (product of the annual volume and number of production years, specified in the Production Scenario screen of the Cost Guide)
- Non-foundry scrap parts: number of parts scrapped by downstream, non-foundry processes

Labor and Setup Costs for Die Casting

Most casting processes use the formulas in this section to determine labor and setup costs.

Die Casting and moldmaking processes use the a special labor cost formula that includes handling cost:

Labor Cost = Labor Time * Labor Rate / Final Yield

Labor cost depends on the following:

- Labor time (see formula below)
- Labor rate (specified as a machine property)
- Final yield (see [Yields For Die Casting](#))

Labor Time = (Cycle Time * Number of Operators * Labor Time Standard) + Labor Handling Time

Labor time depends on the following:

- Cycle time (see process-specific Cycle Time formulas)
- Number of operators (specified as a machine property)
- Labor time standard: specified as the machine property **Labor Time Standard**. This multiplier is used to account for otherwise unaccounted for factors that affect labor time, such as operator fatigue or time spent by the operator for cleaning or maintenance.
- Labor handling time (see formula)

Labor Handling Time = Elapsed Handling Time * Number of Handling Operators

Elapsed handling time and number of handling operators are interpolated from values looked up by mass in the lookup table **tblHandlingTimes**. Labor handling time is 0 for the Melting process. For all casting processes except coremaking processes, the mass that requires handling is Mass Before Machining ([Material Cost and Utilization for Die Casting](#)).

The interpolated value is based on the table rows whose **Max Weight** values straddle the mass that must be handled. If the mass falls below the minimum mass listed in the table, the handling time is considered negligible, and is set to 0. If the mass exceeds the maximum mass listed in the table, aPriori uses the values in the row with the maximum mass.

$$\text{Amortized Batch Setup} = \frac{\text{Setup Time} * (\text{Labor Rate} + \text{Direct Overhead Rate})}{\text{Batch Size}}$$

Batch setup cost per part depends on the following:

- Setup time (specified as the machine property **Setup Time**)
- Labor rate (specified by the machine property **Labor Rate**)
- Direct overhead rate (see [Direct and Indirect Overhead](#))
- Batch size (specified in the **Production Scenario** screen of the Cost Guide)

Gating System Model for Die Casting

The properties of the gating system affect material utilization and melting overhead, as well as finishing costs. See the following sections:

- [Material Cost and Utilization for Die Casting](#)
- [Finishing Formulas for Die Casting](#)

Finishing costs are affected by the cross-sectional area and volume of ingates and risers.

Material utilization and melting costs are affected by the total volume of the gating system. See the following sections:

- [Gating System Formulas for High Pressure Die Casting](#)
- [Gating System Formulas for Gravity Die Casting](#)

Gating System Formulas for High Pressure Die Casting

The gating system is modeled with the following formulas:

$$\text{Total Gating Volume} = \text{Runner Volume} + \text{Total Overflow Volume}$$

The total volume of the gating system is the sum of the following:

- Runner volume (see formula)
- Total overflow volume (see formula)

$$\text{Runner Volume} = \text{Runner Area} * \text{Runner Length} * \text{Number of Runners}$$

Runner volume is the product of the following:

- Runner area. This is the cross-sectional area of the runner (see formula).
- Runner length: This is the length of the mold base. By default, mold length is based on the part dimensions, the number of cavities, and the number of required side cores. Users can specify the mold length with the setup option **Mold Base Size – Length** (see [High Pressure and Gravity Die Casting Process Inputs](#)).
- Number of runners. By default, this is 1 if the mold has a single cavity; for molds with multiple cavities, the default number of runners is half the number of cavities

(rounded up to the nearest whole number of runners). Users can specify the number of runners with the setup option **Number of Runners** (see [High Pressure and Gravity Die Casting Process Inputs](#)).

$$\text{Runner Area} = (\text{Ingate Area} * \text{Ingate Area To Runner Area}) / \text{Number of Runners}$$

Area of a single runner depends on the following:

- Ingate area (see formula)
- Ingate Area to Runner Area. This is the ratio of the ingate cross-sectional area to the runner cross-sectional area. The ratio is 1.4 in starting point VPEs. VPE administrators can customize this value with the cost model variable **ingateAreaToRunnerArea**.
- Number of runners. By default, this 1 if the mold has a single cavity; for molds with multiple cavities, the default number of runners is half the number of cavities (rounded up to the nearest whole number of runners). Users can specify the number of runners with the setup option **Number of Runners** (see [High Pressure and Gravity Die Casting Process Inputs](#)).

$$\text{Ingate Area} = (\text{Volume Before Machining} + \text{Overflow Volume per Cavity}) / (\text{Inject Time} * \text{Gate Velocity})$$

Ingate area is derived, in part, from the optimum pour time. It depends on the following:

- Volume before machining (see formula)
- Overflow volume per cavity (see formula)
- Inject time (see formula)
- Gate velocity. This is looked up by material type and part surface quality in the lookup table **tblGateVelocity**. By default, part surface quality is **3 (Some porosity, some knit lines)**, but users can override the default with setup option **Surface Quality of Part** (see [High Pressure and Gravity Die Casting Process Inputs](#)). If there is no matching entry, the table's minimum gate velocity is used.

Material Type	Part Surface Quality	Gate Velocity (m / s)
Aluminum	1.00	20.00
Aluminum	3.00	40.00
Aluminum	5.00	60.00
Aluminum Bronze	1.00	20.00
Aluminum Bronze	3.00	40.00
Aluminum Bronze	5.00	60.00
Brass	1.00	20.00
Brass	3.00	35.00
Brass	5.00	50.00
Bronze	1.00	20.00
Bronze	3.00	35.00
Bronze	5.00	50.00
Lead	1.00	20.00
Lead	3.00	35.00
Lead	5.00	50.00
Magnesium	1.00	40.00
Magnesium	3.00	50.00
Magnesium	5.00	60.00
Manganese Bronze	1.00	40.00
Manganese Bronze	3.00	50.00
Manganese Bronze	5.00	60.00
Silicon Brass	1.00	20.00
Silicon Brass	3.00	35.00
Silicon Brass	5.00	50.00
Zinc	1.00	30.00
Zinc	3.00	40.00
Zinc	5.00	50.00
Zinc-Aluminum	1.00	30.00
Zinc-Aluminum	3.00	40.00
Zinc-Aluminum	5.00	50.00

Inject Time = Solidification Constant * (Inject Temp – Liquidus Temp + (Percent Solids * Latent Heat Constant)) / (Liquidus Temp – Mold Temp) * Average Thickness

This is the optimum time to pour the material. It depends on the following:

- Solidification constant. This is the time per unit thickness required for the mold to solidify the part's material (that is, the reciprocal of the solidification rate). It is .034 sec/mm in starting point VPEs. VPE administrators can customize the value with the cost model variable **solidificationConstantHPDC**.
- Inject temperature (temperature of the metal as it enters the cavity, specified by a material property)
- Liquidus temperature (minimum temperature at which the metal can flow, specified by a material property)

- Percent solids: This is the amount of solidification that can occur during injection. It is looked up by part surface quality in the lookup table **tblPercentSolids**.

Index	Quality Requirement	Percent Solids
1	Highly Decorative, Class A	5.00
2	Decorative, Class B	15.00
3	Some porosity, some knit lines	25.00
4	Low porosity, poor finish	35.00
5	Machined, Pressure Tight	45.00

By default, part surface quality is **Some porosity, some knit lines**, but users can override the default with setup option **Surface Quality of Part** (see [High Pressure and Gravity Die Casting Process Inputs](#)).

- Latent heat constant: This is 1% of the size of the current material's solidification range (that is, the amount of heat that leaves a given mass of the material when the percentage of the mass that is solid is increased by 1). It is looked up by material type in the lookup table **latentHeatConstant**.

Material Name	Latent Heat Constant (°C)
Aluminum	3.80
Copper	4.70
Lead	2.10
Magnesium	3.70
Zinc	2.50

- Mold temperature (die temperature at injection, specified by a material property)
- Average thickness (average part thickness, determined by GCD extraction)

Total Overflow Volume = Overflow Volume per Cavity * Number of Cavities

Total overflow volume is the product of the following:

- Overflow volume per cavity (see formula)
- Number of cavities (see [Number of Mold Cavities for Die Casting](#))

Overflow Volume per Cavity = Volume Before Machining * Overflow to Part Volume Ratio

Overflow Volume per Cavity is the product of the following:

- Volume Before Machining (see formula)
- Overflow to Part Volume Ratio. This is looked up by part wall thickness (the GCD property **Average Thickness**) in the lookup table **tblOverflowDim**. aPriori uses the entry with the greatest value in the Wall Thickness column that is less than or equal to the part wall thickness (if there is such an entry). If there is no such entry (that is, if the part thickness is below the table's range), aPriori uses the entry with the smallest wall thickness. For decorative or highly decorative parts (that is, parts with surface quality less than 3), aPriori uses the value in the column

Overflow Volume Ratio High. For parts with surface quality 3 or greater, aPriori uses the value in the column Overflow Volume Ratio Low.

Wall Thickness (mm)	Overflow Volume Ratio High	Overflow Volume Ratio Low
0.90	1.50	0.75
1.30	1.00	0.50
1.80	0.50	0.25
2.50	0.25	0.25
3.20	0.10	0.10

By default, part surface quality is 3 (**Some porosity, some knit lines**), but users can override the default with setup option **Surface Quality of Part** (see [High Pressure and Gravity Die Casting Process Inputs](#)).

Volume Before Machining = Part Volume + Metal Chip Volume of Machined Features

Volume before machining is the part volume plus the volume removed by machining. It is the sum of the following:

- Part volume (obtained from GCD extraction)
- Metal chip volume of machined features: derived by summing metal chip volume for each machining operation that is applied to the part. For fully-machined features, this calculation is based on feature volume. For machine-finished features, the calculation is based on the area of the finished surface. The calculation assumes that the depth of material removed during finishing is the value specified by the cost model variable **finishAllowance**.

Gating System Formulas for Gravity Die Casting

The gating system is modeled with the following formulas:

$$\text{Total Gating Volume} = \text{Riser Volume} + \text{Runner Volume} + \text{Ingate Volume} + \text{Sprue Volume} + \text{Sprue Well Volume} + \text{Pouring Basin Volume}$$

The total volume of the gating system is the sum of the following:

- Riser volume (see formula)
- Runner volume (see formula)
- Ingate volume (see formula)
- Sprue volume (see formula)
- Sprue well volume (see formula)
- Pouring basin volume (see formula)

$$\text{Riser Volume} = 1.9 * \text{Shape Factor}^{-0.7} * \text{Part Volume} * \text{Contraction Ratio}$$

This formula is based on the NRL (Naval Research Laboratory) method for determination of riser volume. Riser volume depends on the following:

- Shape factor. This is the ratio of the sum of part length and part width to the maximum thickness of the part (determined by geometry extraction).
- Part volume (determined by geometry extraction)

- Contraction ratio. This is the ratio of the contraction volume percentage for the current material to the contraction volume percentage for steel (looked by material type in the lookup table **tblSolidificationShrinkage**).

Runner Volume = Runner Area * Runner Length * Number of Runners

Runner volume is the product of the following:

- Runner area. This is the cross-sectional area of the runner (see formula).
- Runner length: This is the same as the mold length. It is the product of the number of cavities along the length of the mold (see [Number of Mold Cavities for Die Casting](#)) and the part length, supplemented by twice the value of the cost model variable **edgeBorderPM** (3 inches in starting point VPEs). Additional length is included to accommodate any required slides. The mold length is constrained by the minimum mold length specified by the tool shop variable **Mold Min** (8 inches in starting point VPEs).
- Number of runners. By default, this 1 if the mold has a single cavity; for molds with multiple cavities, the default number of runners is half the number of cavities (rounded up to the nearest whole number of runners). Users can specify the number of runners with the setup option **Number of Runners**.

Runner Area = (Choke Area * Gating Ratio Runner Multiplier) / Number of Runners

Runner cross-sectional area depends on the following:

- Choke area (see formula)
- Gating ratio runner multiplier (looked up by gating ratio in the table **tblGatingDesign**). The gating ratio is 1:2:5 by default, or specified by the setup option Gating Ratio).
- Number of runners. By default, this 1 if the mold has a single cavity; for molds with multiple cavities, the default number of runners is half the number of cavities (rounded up to the nearest whole number of runners). Users can specify the number of runners with the setup option **Number of Runners**.

Choke Area = Pour Weight / (Material Density * Fill Time * Sqrt(2 * Gravitational Acceleration * Effective Sprue Height))

Choke area is derived, in part, from the optimum pour time. It depends on the following:

- Pour weight (see formula)
- Material density (specified by the material property **Density**)
- Fill time (see formula)
- Gravitational acceleration (9800 mm/sec²)
- Effective sprue height. This is the same as the mold width. It is the product of the number of cavities along the width of the mold (see [Number of Mold Cavities for Die Casting](#)) and the part width, supplemented by twice the value of the cost model variable **edgeBorderPM** (3 inches in starting point VPEs). The value is constrained by the minimum mold length specified by the tool shop variable **Mold Min** (8 inches in starting point VPEs).

Fill Time = Number of Cavities * (Fill Time Constant + (Part Volume / Fill Rate))

For materials other than gray iron, optimum pour time depends on the following:

- Number of cavities (see [Number of Mold Cavities for Die Casting](#))
- Fill time constant. This is the portion of the per-cavity fill time that is independent of part volume. It is specified by the cost model variable **fillTimeConstantGravityDieCasting** (15 sec in starting point VPEs).
- Part volume (determined by geometry extraction)
- Fill rate. This is specified by the cost model variable **moldFillRateGravityDieCasting** (120,000mm³/sec in starting point VPEs).

Pour Weight = (Mass Poured Per Cavity * Number of Cavities) / (Estimated Mold Yield / 100)

Pour weight depends on the following:

- Mass poured per cavity (see formula)
- Number of cavities (see [Number of Mold Cavities](#))
- Estimated mold yield. This is specified by the cost model variable **materialYieldGravityDieCasting** (70% in starting point VPEs).

Mass Poured Per Cavity = Volume Before Machining * Material Density

Mass Poured per cavity is the product of the following:

- Volume before machining (see formula)
- Material density (specified by the material property **Density**)

Volume Before Machining = Part Volume + Metal Chip Volume of Machined Features

Volume before machining is the part volume plus the volume removed by machining. It is the sum of the following:

- Part volume (obtained from GCD extraction)
- Metal chip volume of machined features: derived by summing metal chip volume for each machining operation that is applied to the part. For fully-machined features, this calculation is based on feature volume. For machine-finished features, the calculation is based on the area of the finished surface. The calculation assumes that the depth of material removed during finishing is the value specified by the cost model variable **finishAllowance**.

Ingate Volume = Ingate Area * Ingate Length * Number of Ingates

Ingate volume is the product of the following:

- Ingate area (see formula)
- Ingate length (the fraction of part length specified by the cost model variable **ingateLengthToPartLength**—1/10 in starting point VPEs)
- Number of ingates. By default, there is one ingate for every 6 inches of part length, in starting point VPEs. This distance is specified by the cost model variable **ingateGap**. This is the maximum distance between ingates for a given cavity. With the setup option Number of Ingates, you can override the default, and specify the number of ingates explicitly.

Ingate Area = (Choke Area * Gating Ratio Ingate Multiplier) / Number of Ingates

Ingate cross-sectional area depends on the following:

- Choke area (see formula)
- Gating ratio ingate multiplier (looked up by gating ratio in the table **tblGatingRatios**)
- Number of ingates. By default, there is one ingate for every 6 inches of part length, in starting point VPEs. This distance is specified by the cost model variable **ingateGap**. This is the maximum distance between ingates for a given cavity. With the setup option Number of Ingates, you can override the default, and specify the number of ingates explicitly.

**Sprue Volume = (PI / 3) * Effective Sprue Height *
((Sprue Bottom Radius²) + (Sprue Top Radius²) + (Sprue Bottom Radius *
Sprue Top Radius))**

Sprue volume depends on the following:

- Effective sprue height. This is the same as the mold width. It is the product of the number of cavities along the width of the mold (see [Number of Mold Cavities for Die Casting](#)) and the part width, supplemented by twice the value of the cost model variable **edgeBorderPM** (3 inches in starting point VPEs). The value is constrained by the minimum mold length specified by the tool shop variable **Mold Min** (8 inches in starting point VPEs).
- Sprue bottom radius (see formula)
- Sprue top radius (see formula)

Sprue Bottom Radius = sqrt(Sprue Bottom Area / Pi)

Sprue bottom radius is a function of sprue bottom area (see formula).

Sprue Bottom Area = Choke Area * Gating Ratio Sprue Multiplier

Sprue bottom area is the product of the following:

- Choke area (see formula)
- Gating ratio sprue multiplier (looked up by gating ratio in the table **tblGatingRatios**)

Sprue Top Radius = sqrt(Sprue Top Area / Pi)

Sprue top radius depends on sprue top area—see formula.

Sprue Top Area = Sprue Bottom Area * sqrt(Effective Sprue Height / Pouring Basin Depth)

Sprue top area depends on the following:

- Sprue bottom area (see formula)
- Effective sprue height: This is the same as the mold width. It is the product of the number of cavities along the width of the mold (see [Number of Mold Cavities for Die Casting](#)) and the part width, supplemented by twice the value of the cost model variable **edgeBorderPM** (3 inches in starting point VPEs). The value is constrained by the minimum mold length specified by the tool shop variable **Mold Min** (8 inches in starting point VPEs).
- Pouring basin depth (see formula)

Pouring Basin Depth = (Pouring Basin Volume / 2)^(1/3)

The model assumes a box-shaped basin with depth equal to width, and length equal to twice the width, so depth depends only on volume—see formula.

Pouring Basin Volume = (Pour Weight / Metal Density) / Fill Time

Pouring basin volume is assumed to be the volume of metal that passes in one second, given the optimal pouring time. It depends on the following:

- Pour weight (see formula)
- Metal density (specified by the material property **Density**)
- Fill time (see formula)

Sprue Well Volume = Sprue Well Area * Sprue Well Height

Sprue well volume depends on the following:

- Sprue well area (see formula)
- Sprue well height (see formula)

Sprue Well Height = Runner Height * Sprue Well Height to Runner Height Ratio

Sprue well height is the product of the following:

- Runner height (see formula)
- Sprue well height to runner height ratio. This is specified by the cost model variable **sprueWellHeightToRunnerHeight** (2 in starting point VPEs).

Runner Height = sqrt(Runner Area / Runner Aspect Ratio)

Runner height depends on the following:

- Runner area (see formula)
- Runner aspect ratio. This is the ratio of runner width to runner height. It is specified by the cost model variable **runnerAspectRatio** (2 in starting point VPEs).

Sprue Well Area = Pi * (Sprue Well Radius To Well Base Ratio * Sprue Bottom Radius)²

The cross-sectional area of the sprue well is the product of the following:

- Sprue well radius to well base ratio (specified by the cost model variable **sprueWellRadiusToWellBase**—3.5 in starting point VPEs)
- Sprue bottom radius (see formula)

Melting Formulas for Die Casting

Melting costs consist of material cost (see [Material Cost and Utilization for Die Casting](#)), labor cost (see [Labor and Setup Costs for Die Casting](#) and [Cycle Time](#) in this section), direct overhead (see [Direct Overhead](#) in this section), and metal additive cost (see [Additional Direct Costs](#) in this section).

Cycle Time = Process Time * Cycle Time Adjustment Factor

Cycle time is the product of the following:

- Process time (see formula below)

- Cycle time adjustment factor: specified by the cost model variable **cycleTimeAdjustmentFactor**; 1 in aPriori starting point VPEs.

Process Time = Furnace Melting Time / Number of Parts Per Furnace

This is the per-part time to heat the contents of the selected furnace to the pouring temperature. The cost model assumes that the furnace is filled to capacity or nearly to capacity, so as to accommodate the maximal number of parts. Process time depends on the following:

- Furnace melting time (see formula)
- Number of parts per furnace (see formula)

Furnace Melting Time = Furnace Required Energy / Material Transferred Power

This is the time to heat the contents of the selected furnace from ambient temperature to pouring temperature. The cost model assumes that the furnace is filled so as to accommodate the maximal number of parts. Furnace melting time depends on the following:

- Furnace required energy (see formula)
- Material transferred power: this is the rate of heat transfer through the material in the furnace. The cost model calculates this using Fourier's law of heat conduction, assuming a cylindrical furnace whose height is twice its diameter.

Furnace Required Energy = (Furnace Required Heat Energy + Furnace Required Melt Energy + Furnace Required Superheat Energy) * Furnace Factor

This is the energy required to heat the contents of the selected furnace from ambient temperature to pouring temperature. It is the sum of the following:

- Furnace required heat energy (see formula)
- Furnace required melt energy (see formula)
- Furnace required superheat energy (see formula)
- Furnace factor (specified by the machine property **Furnace Factor**)

Furnace Required Heat Energy = Specific Heat Room Temperature * (Solidus Temperature – Ambient Temperature) * Total Required Melted Mass

This is the energy required to heat the contents of the selected furnace from ambient temperature to solidus temperature. It depends on the following:

- Specific heat room temperature (specified by the material property **Specific Heat at Room Temperature**)
- Solidus temperature (specified by the material property **Solidus Temp**)
- Ambient temperature (specified by the cost model variable **ambientTemp**, 21 degrees Celsius in starting point VPEs)
- Total required melted mass (see formula)

Furnace Required Melt Energy = Latent Heat * Total Required Melted Mass

This is the energy required to heat the contents of the selected furnace from solidus temperature to liquidus temperature (that is, heated to the point at which the contents is entirely liquid). It is the product of the following:

- Latent heat: Energy per unit mass required to change the selected material completely from solid to liquid, once heated to solidus temperature.
- Total required melted mass (see formula)

Furnace Required Superheat Energy = Specific Heat Solidus Temperature * (Pouring Temperature – Liquidus Temperature) * Total Required Melted Mass

This is the energy required to superheat the contents of the selected furnace from liquidus temperature to pouring temperature. It depends on the following:

- Specific heat solidus temperature (specified by the material property **Specific Heat at Solidus Temperature**)
- Pouring temperature (specified by the material property **Injection Temp**)
- Liquidus temperature (specified by the material property **Liquidus Temp**)
- Total required melted mass (see formula)

Total Required Melted Mass = Number of Parts Per Furnace * Mass Poured

This is the minimum mass of material required to produce the maximum number of parts that can be produced by the selected furnace. It is the product of the following:

- Number of parts per furnace (see formula)
- Mass poured: this is the mass poured per part (see formula).

Number of Parts Per Furnace = rounddown(Furnace Mass Capacity / Mass Poured)

This the maximum number of parts that can be produced by the selected furnace. It depends on the following:

- Furnace mass capacity (product of material density and the machine property **Furnace Capacity**)
- Mass poured: this is the mass poured per part (see formula).

Direct Overhead Cost = (Mass Poured * Melting Rate) / Final Yield

Direct overhead per part depends on the mass poured per part.

Direct overhead depends on the following:

- Mass Poured: mass poured per part (see formula)
- Melting rate: melting cost per unit mass (see formula)
- Final yield (see [Yields For Die Casting](#))

Mass Poured = Mass Before Machining + Mass Waste + Mass Bad Parts + Mass Loss

Mass poured is the sum of the following:

- Mass before machining (see [Material Cost and Utilization for Die Casting](#))
- Mass waste (see [Material Cost and Utilization for Die Casting](#))
- Mass bad parts (see [Material Cost and Utilization for Die Casting](#))
- Mass loss (see [Material Cost and Utilization for Die Casting](#))

Melting Rate = Total Annual Factory Cost / Annual Mass Melted Metal

Melting rate depends on the following:

- Total annual factory cost (see formula)

- Annual mass melted metal (see formula)

Total Annual Factory Cost = Annual Labor Cost + Annual Direct Cost + Annual Indirect Cost

Total annual factory cost is the sum of the following:

- Annual labor cost (see formula)
- Annual direct cost (see formula)
- Annual indirect cost (see formula)

Annual Labor Cost = Annual Earned Machine Hours * Number of Operators * Labor Rate

Annual labor cost is the product of the following:

- Annual earned machine hours (see [Annual Earned Machine Hours](#))
- Number of operators (specified by the machine property **Number of Operators**)
- Labor rate: this is the product of the machine property **Labor Rate** and cost model variable **laborRateAdjustmentFactor** (1 in starting point VPEs).

Annual Direct Cost = Depreciation Cost + Maintenance Cost + Annual Energy Cost + Supplies Cost + Imputed Interest Cost

Annual direct cost is the sum of the following:

- Depreciation cost (see [Annual Depreciation](#))
- Maintenance cost (see [Annual Maintenance](#))
- Annual energy cost (see formula)
- Supplies cost (specified by the machine property **Supplies Cost**)
- Imputed interest cost (see [Imputed Interest](#))

Annual Energy Cost = Annual Mass Melted Metal * Melting Cost Per Mass

Annual energy cost is the product of the following:

- Annual mass melted metal (see formula)
- Melting cost per mass (see formula)

Annual Mass Melted Metal = Furnace Productivity * Material Density * Annual Earned Machine Hours

Annual mass melted metal is the product of the following:

- Furnace productivity: this is the machine property **Furnace Capacity** divided by the furnace melting time (see formula above).
- Material density (specified by the material property **Density**)
- Annual earned machine hours (see [Annual Earned Machine Hours](#))

Melting Cost Per Mass = Electricity Rate * Unit Melting Energy

Melting cost per mass is the product of the following:

- Electricity rate (specified by the VPE variable **Electricity Rate**)
- Unit melting energy (see formula)

$$\text{Unit Melting Energy} = (\text{Latent Heat} + \text{Specific Heat at Solidus Temperature} * (\text{Pouring Temperature} - \text{Liquidus Temperature}) + \text{Specific Heat at Room Temperature} * (\text{Solidus Temperature} - \text{Ambient Temperature})) * \text{Furnace Factor}$$

Unit melting energy depends on the following:

- Latent heat (specified by the material property **Heat of Fusion**)
- Specific heat at solidus temperature (specified by the material property **Specific Heat at Solidus Temperature**)
- Pouring temperature (specified by the material property **Injection Temp**)
- Liquidus temperature (specified by the material property **Liquidus Temp**)
- Specific heat at room temperature (specified by the material property **Specific Heat at Room Temperature**)
- Solidus temperature (specified by the material property **Solidus Temp**)
- Ambient temperature (specified by the cost model variable **Ambient Temp**—21 degrees Celsius in starting point VPEs)
- Furnace factor (specified by the machine property **Furnace Factor**)

$$\text{Annual Indirect Cost} = \text{Facility Cost} + \text{Support Services Cost}$$

Annual indirect cost is the sum of the following:

- Facility cost (see [Facilities Cost](#))
- Support services cost (see [Support Services Cost](#))

$$\text{Additional Direct Costs} = (\text{Rough Mass} * \text{Metal Additive Rate}) / \text{Final Yield}$$

Additional direct costs consist of metal additive cost, and is the product of the following:

- Rough mass (see [Material Cost and Utilization for Die Casting](#))
- Metal additive rate is the cost of metal additive per Kg of rough mass. By default, this is looked up by additive type in the table **tblMetalAdditives**. Additive type is either the additive named **Default** in the lookup table (with a rate of \$0.22 in starting point VPEs), or else the type specified by the user with the PSO **Metal Additive Type**. You can override the looked-up rate with the PSO **Metal Additive Rate** (see [User Inputs for Die Casting](#)).
- Final yield (see [Yields For Die Casting](#))

Cleaning Formulas for Die Casting

The **Cleaning** process uses the formulas below.

$$\text{Cycle Time} = \text{Process Time} * \text{Cycle Time Adjustment Factor}$$

Cycle time is the product of the following:

- Process time (see formula below)
- Cycle time adjustment factor: specified by the cost model variable **cycleTimeAdjustmentFactor**; 1 in aPiori starting point VPEs.

Process Time = Blast Time + Reorient Time

The cleaning process time is the sum of the following:

- Blast Time (see formula below)
- Reorient Time. This is 0 for Tumble Blast machines. For Table Blast and Room Blast, this is the product of handling time per operator (elapsed handling time) and number of handling operators, which are interpolated from values looked up by mass in the lookup table **tblHandlingTimes**. Mass, for these purposes, is Mass Before Machining (see [Material Cost and Utilization for Die Casting](#)).

Blast Time = (Time per Load / Number of Parts in Load) * Design Complexity Factor

Blast time (formula Tumble Blast Cycle Time, Table Blast Cycle Time, or Room Blast Cycle Time) depends on the following:

- Time per load. For tumble and table blast machines, this is specified by the machine property **Time per Load**. For Room Blast machines, see the formula below.
- Number of parts per load. This is the maximum number of parts that fall within the machine's limits for weight and volume (for tumble blast machines) or for weight and area (for table blast machines). For room blast machines, the number of parts is always 1. For more information, see [Cleaning Machine Selection](#).
- Design complexity factor (see [Design Complexity Factor](#))

Time per Load for Room Blast machines = (External Surface Area / External Surface Blast Rate) + (Internal Surface Area / Internal Surface Blast Rate)

For room blast cleaning, process time depends on the following:

- External surface area (area of all surfaces for which there is a non-obstructed **IS_ACCESSIBLE_FROM** relation)
- External surface blast rate (specified by the machine property **External Surface Blast Rate**)
- Internal surface area (area of all surfaces for which there is no non-obstructed **IS_ACCESSIBLE_FROM** relation)
- Internal surface blast rate (specified by the machine property **Internal Surface Blast Rate**)

Additional Direct Costs = Shot Abrasive Cost / Final Yield

Additional direct costs consist of the cost for the abrasive used in the shot stream (including abrasive used for scrapped parts, amortized over all the parts in the current production scenario):

- Shot abrasive cost (see formula below)
- Final yield (see [Yields For Die Casting](#))

Shot Abrasive Cost = Shot Consumption * Blast Power * Shot Unit Cost * Blast Time

Shot abrasive cost is the product of the following:

- Shot consumption (specified by the machine property **Shot Consumption**)

- Blast power (specified by the machine property **Blast Power**)
- Shot unit cost (specified by the tool shop variable **shotUnitCost**)
- Blast time (see formula above)

Finishing Formulas for Die Casting

The **Finishing** process relies on the formulas below.

Cycle Time = Process Time * Cycle Time Adjustment Factor

Cycle time is the product of the following:

- Process time (see formula below)
- Cycle time adjustment factor: specified by the cost model variable **cycleTimeAdjustmentFactor**; 1 in aPiori starting point VPEs.

Process Time = Grinding Time * Design Complexity Factor

Process time is the product of the following:

- Machine load and unload time (specified as a machine property)
- Grinding time (see formula below)
- Design complexity factor (see [Design Complexity Factor](#))

Grinding Time = (Parting Line Grind Volume / Grinding Speed Material Parting Line) + ((Ingate Grind Volume + Riser Grind Volume) / Grinding Speed Material Gating)

Grinding time is the quotient of the following:

- Parting line grind volume (see formula)
- Grinding speed material parting line: this is the product of the machine property **Grinding Speed Parting Line** and an adjustment factor looked up by material cut code in the lookup table **tblGrindingSpeedMaterialFactor**.
- Ingate grind volume (see formula)
- Riser grind volume (see formula)
- Grinding speed material gating: this is the product of the machine property **Grinding Speed Gating** and an adjustment factor looked up by material cut code in the lookup table **tblGrindingSpeedMaterialFactor**.

Parting Line Grind Volume = Parting Line Length to Grind * Parting Line Height * Parting Line Thickness

Parting line length to grind is the product of the following:

- Parting line length to grind: this is the product of the **Projected Perimeter** property of the Parting Line GCD and the fraction of the parting line to grind, specified by the setup option **Percent Parting Line to Grind**—1 by default.
- Parting line height: interpolated based on values looked up by Mass Before Machining (see [Material Cost and Utilization for Die Casting](#)) in the lookup table **tblGrindingDimensions**.
- Parting line thickness: interpolated based on values looked up by Mass Before Machining (see [Material Cost and Utilization for Die Casting](#)) in the lookup table **tblGrindingDimensions**.

Ingate Grind Volume = Total Ingate Area To Grind * Ingate Height

Ingate grind volume is the product of the following:

- Total ingate area to grind (see formula)
- Ingate height: interpolated based on values looked up by Mass Before Machining (see [Material Cost and Utilization for Die Casting](#)) in the lookup table `tblGrindingDimensions`.

Total Ingate Area to Grind = Total Ingate Area * Percent Ingate Area to Grind

Total ingate area to grind is the product of the following:

- Total ingate area: this is the product of Ingate Area (see [Gating System Formulas for Gravity Die Casting](#)) and the number of ingates. Number of ingates is specified by the setup option **Number of Ingates** for Gravity Die Casting.
- Percent ingate area to grind: fraction of the ingate area to grind, specified by the setup option **Percent Ingate Area to Grind**—1 by default.

Riser Grind Volume = Riser Base Area To Grind * Riser Height

Ingate grind volume is the product of the following:

- Riser base area to grind (see formula)
- Riser height: interpolated based on values looked up by Mass Before Machining (see [Material Cost and Utilization for Die Casting](#)) in the lookup table `tblGrindingDimensions`.

Riser Base Area to Grind = Riser Base Area * Percent Riser Area to Grind

Total ingate area to grind is the product of the following:

- Riser base area (see formula)
- Percent riser area to grind: fraction of the ingate area to grind, specified by the setup option **Percent Riser Area to Grind**—1 by default.

Riser Base Area = Pi * Riser Radius²

Riser base area depends on riser radius, which is half the riser diameter. The formula for riser diameter is below.

Riser Diameter = (8 * Riser Volume) / Pi)^{1/3}

Because the riser is assumed to be cylindrical with height equal to half the diameter, riser diameter can be determined from riser volume alone. The formula for Riser Volume is below.

Riser Volume = 1.9 * Shape Factor^{-0.7} * Part Volume * Contraction Ratio

This formula is based on the NRL (Naval Research Laboratory) method for determination of riser volume. Riser volume depends on the following:

- Shape factor. This is the ratio of the sum of part length and part width to the maximum thickness of the part (determined by geometry extraction).
- Part volume (determined by geometry extraction)
- Contraction ratio. This is the ratio of the contraction volume percentage for the current material to the contraction volume percentage for steel (looked by material type in the lookup table `tblSolidificationShrinkage`).

Visual Inspection Formulas for Die Casting

The **Visual Inspection** process relies on the formulas below.

$$\text{Cycle Time} = \text{Process Time} * \text{Cycle Time Adjustment Factor}$$

Cycle time is the product of the following:

- Process time (see formula below)
- Cycle time adjustment factor: specified by the cost model variable **cycleTimeAdjustmentFactor**; 1 in aPriori starting point VPEs.

$$\text{Process Time} = (\text{Internal Examination Time} + \text{External Examination Time}) * \text{Design Complexity Factor}$$

Process time depends on the following:

- Internal examination time (see formula)
- Internal examination time (see formula)
- Design complexity factor (see [Design Complexity Factor](#))

$$\text{Internal Examination Time} = \text{Internal Inspection Rate} * \text{Internal Surface Area} * \text{core factor}$$

Internal examination time is the product of the following:

- Internal inspection rate: looked up by weight in the lookup table **tblVisualInspection**.

Max Weight (kg)	Internal Inspection Rate (min / m ²)	External Inspection Rate (min / m ²)
10.00	1.78	1.34
25.00	1.70	1.28
50.00	1.64	1.23
100.00	1.59	1.19
250.00	1.52	1.14
500.00	1.47	1.10
1,000.00	1.42	1.06
2,500.00	1.35	1.01
5,000.00	1.31	0.98
10,000.00	1.26	0.95

- Internal surface area. This is the total area of all internal surfaces. Internal surfaces are those for which there is no **Normal**, **Parallel**, or **Oblique IS_ACCESSIBLE_FROM** relation.
- Core factor. This is a factor that reflects the extra time required for inspection of parts with cored features. For parts with no cored features, the factor is 1. For parts with one cored feature, the factor is specified by the cost model variable **singleCoreInspectionFactor** (1.5 in starting point VPEs); for parts with two or more cored features, the factor is specified by the cost model variable **doubleCoreInspectionFactor** (2 in starting point VPEs) plus an additional **multiCoreInspectionFactor** (0.1 in starting point VPEs) for each cored feature.

$$\text{External Examination Time} = \text{External Inspection Rate} * \text{External Surface Area} * \text{core factor}$$

External examination time is the product of the following:

- External inspection rate: looked up by weight in the lookup table **tblVisualInspection**.
- External surface area. This is the total area of all external surfaces. External surfaces are those for which there is a **Normal**, **Parallel**, or **Oblique IS_ACCESSIBLE_FROM** relation.
- Core factor. This is a factor that reflects the extra time required for inspection of parts with cored features. For parts with no cored features, the factor is 1. For parts with one cored feature, the factor is specified by the cost model variable **singleCoreInspectionFactor** (1.5 in starting point VPEs); for parts with two or more cored features, the factor is specified by the cost model variable **doubleCoreInspectionFactor** (2 in starting point VPEs) plus an additional **multiCoreInspectionFactor** (0.1 in starting point VPEs) for each cored feature.

Design Complexity Factor

A part's design complexity factor is used to calculate process time for Cleaning, Finishing, and Visual Inspection (see [Cleaning Formulas for Die Casting](#), [Finishing Formulas for Die Casting](#), and [Visual Inspection Formulas for Die Casting](#)). It is a number between the value of the cost model variable **lowComplexityAdjustment** (0.9 in starting point VPEs) and the value of the cost model variable **extraHighComplexityAdjustment** (1.3 in starting point VPEs).

aPriori determines a part's complexity factor by considering the ratio of the part's surface area to its volume. We refer to a part's surface-area-to-volume ratio as the part's *modulus*.

Modulus of a Part = Part Surface Area / Part Volume

The complexity factor is determined based on an additional ratio: the ratio of the part's modulus to the modulus of a canonical simple part with the same volume. We refer to this ratio as the *modulus ratio*. The greater the modulus ratio, the greater the part complexity.

Modulus Ratio of a Part with Volume V = Part Modulus / Modulus of Canonical Simple Part with Volume V

To serve as canonical simple part with a given volume, V, the cost model uses a cylinder of volume V whose height is equal to its diameter. (The cylinder of a given volume with the smallest surface area is the one whose height equals its diameter.) The diameter of such a cylinder is given by $D = \sqrt[3]{(4V/\pi)}$, and its modulus is 6/D.

The cost model divides possible modulus ratio values into ranges, and associates with each such range a complexity factor range. In starting point VPEs, the association is as follows:

Modulus Ratio Range	Complexity Factor Range
0-0.9	0.9
0.9-1.0	0.9-1.0
1.0-2.5	1.0-1.1
2.5-4.0	1.1-1.2
4.0-10.0	1.2-1.3

≥10.0	1.3
-------	-----

Note that any modulus ratio less than or equal to 0.9 maps to complexity factor 0.9, and any modulus ratio greater than or equal to 10.0 maps to complexity factor 1.3. In other cases, the calculation of the complexity factor involves linear interpolation within these ranges. For example, if the modulus ratio is halfway between the bottom and the top of a modulus ratio range, then the complexity factor lies half way between the bottom and the top of the corresponding complexity factor range.

In general, if the modulus ratio is a certain fraction of the way from the bottom of a modulus ratio range to the top of that range, then the complexity factor is that fraction of the way from the bottom of the corresponding complexity factor range to the top of that range.

The table below summarizes the thresholds that are used to define these ranges. The cost model variables **lowComplexityAdjustment** and **optimumComplexityAdjustment** specify thresholds for both modulus ratios and complexity factors. Note that any modulus ratio less than or equal to **lowComplexityAdjustment** maps to **lowComplexityAdjustment**, and any modulus ratio greater than or equal to **extraHighModulusRatio** maps to **extraHighComplexityAdjustment**.

Modulus Ratio Threshold		Complexity Factor Threshold	
Cost Model Variable	Starting Point VPE Value	Cost Model Variable	Starting Point VPE Value
lowComplexityAdjustment	0.9	lowComplexityAdjustment	0.9
optimumComplexityAdjustment	1.0	optimumComplexityAdjustment	1.0
mediumModulusRatio	2.5	mediumComplexityAdjustment	1.1
highModulusRatio	4.0	highComplexityAdjustment	1.2
extraHighModulusRatio	10.0	extraHighComplexityAdjustment	1.3

High Pressure Die Casting and Gravity Die Casting Process Formulas

The cost model for these processes rely on the formulas below.

Cycle Time

Cycle Time = Process Time * Cycle Time Adjustment Factor

Cycle time is the product of the following:

- Process time (see formula below)
- Cycle time adjustment factor: specified by the cost model variable **cycleTimeAdjustmentFactor**; 1 in aPiori starting point VPEs.

Process Time = (Load Insert Time + Ladle Time + Injection Time + Cool Time + Ejection Time + Lube Time) / Number of Cavities

Process time is a function of the following:

- Load insert time (increases with the number of insert cores)

- Ladle time (increases with part volume, if the material's associated chamber type is cold; 0 otherwise)
- Injection time (increases with number of mold cavities and average part thickness; also depends on material injection and melting temperatures)
- Cool time (increases with maximum part thickness and material cooling factor; decreases with ratio of part surface area to projected parting area)
- Ejection time (see formula)
- Lube time (increases with part length and width)
- Number of cavities (see [Number of Mold Cavities for Die Casting](#))

Note that for high pressure die casting, cleaning is assumed to be performed by the operator on one part while the machine is cycling on the next.

Ejection Time = Mold Open Time + Hydraulic Slide Time + Ejector Plate Time + Part Removal Time + Mold Close Time

Ejection time is the sum of the following:

- Mold open time (see formula)
- Hydraulic slide time: (see formula)
- Ejector plate time (see formula)
- Part removal time: If the setup option Part Eject Method is set to **Gravity** (the default in starting point VPEs), the part removal time is the value of the cost model variable **gravityDropTime** (1.25 seconds in starting point VPEs). Otherwise, part removal time is the value of the cost model variable **robotGrabTime** (2.5 seconds in starting point VPEs).

Mold Open Time = Travel Distance / Max Machine Velocity

Mold open time depends on the following:

- Travel distance: see Travel Distance, below.
- Max machine velocity: see formula.

Travel Distance

Travel distance for mold open or close is generally 3 or 4 times the part height:

- If the setup option Part Eject Method is set to **Gravity** (the default in starting point VPEs), the travel distance is generally the product of part height and the cost model variable **nominalHeightFactor** (3 in starting point VPEs):

$$\text{Travel Distance} = \text{Part Height} * \text{Nominal Height Factor}$$

- If the setup option Part Eject Method is set to **Robotic**, the travel distance is generally the product of the following:
 - Part height
 - Sum of the cost model variables **nominalHeightFactor** (3 in starting point VPEs) and **roboticClearanceFactor**(1 in starting point VPEs)

$$\text{Travel Distance} = \text{Part Height} * (\text{Nominal Height Factor} + \text{Robotic Clearance Factor})$$

See also Part Eject Method in [High Pressure and Gravity Die Casting Process Inputs](#).

$$\text{Max Machine Velocity} = \frac{(\text{Dry Cycle Stroke Factor} * \text{Max Tie Bar Distance} * 2)}{\text{Dry Cycle Time}}$$

The speed of travel during mold open and close is derived from the following:

- Dry cycle stroke factor: this is the fraction of the maximum tie bar distance that equals the stroke length. The fraction is specified by the cost model variable **dryCycleStrokeFactor** (0.7 in starting point VPEs).
- Max tie bar distance: this the larger of the machine properties **Tie Bar Distance, H** and **Tie Bar Distance, V**.
- Dry cycle time: specified by the machine property **Dry Cycle Time**.

$$\text{Hydraulic Slide Time} = (\text{Hydraulic Slide Length} / \text{Slide Cycle Rate}) * 2$$

A slide for a given undercut feature is required to be hydraulic (as opposed to mechanical) if the platen movement required to clear the mechanical slide from the undercut exceeds the mold open stroke. The presence of hydraulic slides contributes to the total ejection time because, unlike mechanical slides, hydraulic slides are retracted only after the mold is opened.

Hydraulic slide time depends on the following:

- Hydraulic slide length: this is 0 if hydraulic slides are unnecessary. If hydraulic slides are necessary, the hydraulic slide length is the maximum undercut depth plus some clearance (0.5 inch if there are multiple cavities, 5mm otherwise).
- Cycle rate per slide: this is the rate at which the hydraulic slides can move, specified by the cost model variable **slideCycleRate** (100mm per second in starting point VPEs).

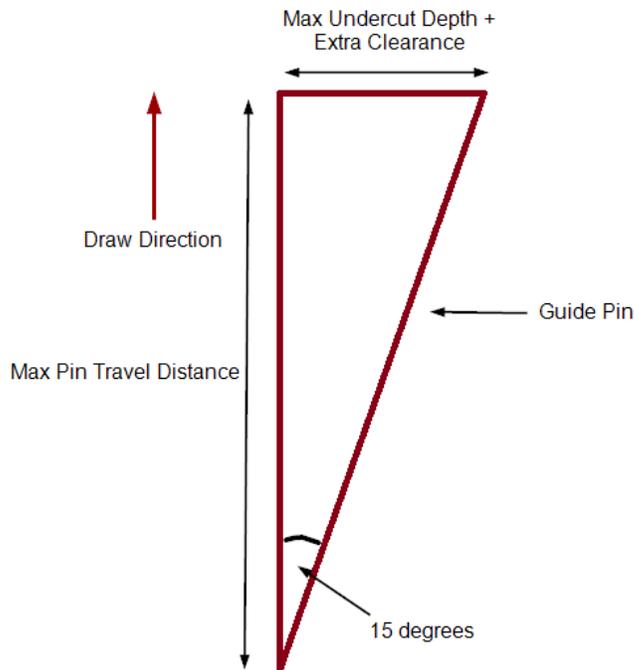
Hydraulic slides are necessary if and only if the following condition holds:

$$\text{Max Pin Travel Distance} > \text{Machine Opening Stroke}$$

Here, Machine Opening Stroke is the value of the machine property **Opening Stroke**.

Max Pin Travel Distance is the distance along the draw direction that the platen would have to travel in order to retract a mechanical slide from the part's deepest undercut. The cost model assumes that a retracting mechanical slide is guided by a pin that makes an angle of 15 degrees with the draw direction. If U is the maximum undercut depth (perpendicular to the draw direction) plus clearance (0.5 inch if there are multiple cavities, 5mm otherwise), then the required platen motion has a length along the draw direction of $U/\tan(15)$:

$$\text{Max Pin Travel Distance} = (\text{Max Undercut Depth} + \text{Extra Clearance}) / \tan(15)$$



If the motion required for a mechanical slide (Max Pin Travel Distance) exceeds the value of the machine property **Opening Stroke**, then hydraulic slides are necessary for the part.

Ejector Plate Time = (Part Height * Ejector Distance Factor) / Max Machine Velocity

Ejector plate time depends on the following:

- Part height: determined by geometry extraction. Part height is measure along the draw direction.
- Ejector distance factor: this is the multiple of part height that equals the distance an ejector pin should move in order to eject the part. It is specified by the cost model variable **ejectorDistanceFactor** (3 in starting point VPEs).
- Max machine velocity: see formula.

Mold Close Time = Travel Distance / Max Machine Velocity

Mold close time depends on the following:

- Travel distance: see Travel Distance, above.
- Max machine velocity: see formula.

Trim Formulas for Die Casting

The cost model for this process relies on the formulas below.

Cycle Time = Process Time * Cycle Time Adjustment Factor

Cycle time is the product of the following:

- Process time (see formula below)

- Cycle time adjustment factor: specified by the cost model variable **cycleTimeAdjustmentFactor**; 1 in aPriori starting point VPEs.

Process Time = Machine Cycle Time + Load Time + Unload Time

Process time is a function of the following:

- Machine cycle time (specified by the machine property **Cycle Time**)
- Load time (looked up by part weight in the lookup table **materialHandling**)
- Unload time (looked up by part weight in the lookup table **materialHandling**)

Load Time (s)	Unload Time (s)	Weight (kg)
10.00	5.00	0.45
15.00	5.00	4.55
20.00	15.00	22.73
30.00	20.00	45.45
40.00	23.00	113.64
50.00	27.00	227.27
60.00	30.00	454,545,454.09

Core Refractory Coating for Die Casting

This process occurs multiple times in a costing when at least one core receives multiple coats (see [Number of Coating Applications](#)). The number of times the process occurs is the number, N , of coats applied to that core that has the greatest number of coats. There are N instances of Core Refractory Coat, where the i^{th} instance includes the cores that receive at least i coating applications, for all i between 1 and N .

Cycle Time = Process Time * Cycle Time Adjustment Factor

Cycle time is the product of the following:

- Process time: this is the sum of the times required to coat each core that receives a coat in the current instance of this process. (If this is the i^{th} instance, all cores that receive at least i coats are included.) See the formula for **Process Time Core Refractory Coat**, below.
- Cycle time adjustment factor: specified by the cost model variable **cycleTimeAdjustmentFactor**; 1 in aPriori starting point VPEs.

Process Time Core Refractory Coat = (Total Surface Area / Application Rate per Mold) / Number of Operators

This is the time required to apply one coat to the core for a given cored feature. It depends on the following:

- Total surface area: this is the area covered by one coat applied to the core for the given feature. It is 0 the core is not coated. For Voids, it is **Surface Area**. For holes, it is the sum of the values of **Finished Area** for all the feature's descendent surfaces. (Descendent GCDs include children, children's children, and so on, recursively.) For Combo Voids, it is the sum of the values of **Finished Area** for all the feature's descendent surfaces, as well as **Surface Area** for all the feature's descendent voids.

- Application rate: this is looked up by [Application Method](#) in the lookup table **tblRefractoryCoating**.

Application Method	Application Rate (m ² / min)	Average Output Volume (L / min)
Brushing	0.28	2.00
Flow Coating	3.85	25.00
Spraying	5.13	6.00

The value is converted to square millimeters per second for use in this formula.

- Number of operators: by default, this is specified by the cost model variable **defaultMoldRefractoryCoatingNumOperators**. (1 in starting point VPEs). Users can override the default on a per-part GCD with the setup option [Number of Operators](#).

This value is rounded up to a whole number of seconds.

Additional Direct Costs

Additional direct costs include the cost for the volume of refractory coating material used for all cores that receive a coat in the current instance of this process. (If this is the i^{th} instance, all cores that receive at least i coats are included.) See the formula for **Additional Direct Costs Core Refractory Coat**, below.

$$\text{Additional Direct Costs Core Refractory Coat} = \frac{(\text{Coating Volume} * \text{Refractory Coating Cost} * \text{Number of Operators})}{\text{Final Yield}}$$

This is the cost for the volume of refractory coating material used for one coat of the core for a given coated core. It depends on the following:

- Coating volume: volume of refractory coating material applied to the core by one operator during the current process. See formula.
- Refractory coating cost: unit cost of the coating material, specified by the toolshop variable **refractoryCoatingCost**.
- Number of operators: by default, this is specified by the cost model variable **defaultCoreRefractoryCoatingNumOperators**. (1 in starting point VPEs). Users can override the default on a per-part basis with the setup option [Number of Operators](#).
- Final yield (see [Yields for Sand Casting](#))

Coating Volume = Process Time * Coating Output Rate

This is the volume of refractory coating material applied to the core by one operator during the current process. It is the product of the following:

- Process time (see formula)
- Coating output rate: this is the volume per unit time of coating material that is expended during application. It is looked up by [Application Method](#) in the lookup table **tblRefractoryCoating**.

Application Method	Application Rate (m ² / min)	Average Output Volume (L / min)
Brushing	0.28	2.00
Flow Coating	3.85	25.00
Spraying	5.13	6.00

This value is converted to liters per second for use in this formula.

Refractory Coat Oven Dry for Die Casting

Coated cores that are small enough to fit in some available oven are assumed to be oven dried. So this process is included when at least one coated core fits in an oven (see [Refractory Coat Oven Dry Machine Selection](#)).

This process occurs multiple times in a costing when at least one oven-dried core receives multiple coats (see [Number of Coating Applications](#)). The number of times the process occurs is the number, N , of coats applied to that oven-dried core that has the greatest number of coats. The i^{th} instance of the oven-dry process includes the cores that receive at least i coating applications, for all i between 1 and N .

Cycle Time = Process Time * Cycle Time Adjustment Factor

Cycle time is the product of the following:

- Process time (see formula below)
- Cycle time adjustment factor: specified by the cost model variable `cycleTimeAdjustmentFactor`; 1 in aPriori starting point VPEs.

Process Time = Oven Dry and Cool Time * Number Oven Cycles Required

This is the time to dry and cool one part's oven-dried cores. If this is the i^{th} occurrence of Refractory Coat Oven Dry, this is the time to dry and cool those oven-dried cores that have at least i coats. Note that the cost model assumes that each oven cycle processes a full load. Process time is the product of the following:

- Oven dry and cool time: this is the time required to dry and cool one machine load of cores. By default, it is specified by the cost model variable `defaultOvenDryAndCoolTime` (19 minutes in starting point VPEs). Users can override the default of a per-part basis with the setup option [Oven Dry and Cool Time](#).
- Number of oven cycles required: this is the number of machine loads required to accommodate one part's oven-dried cores. This value can be fractional. If this is the i^{th} occurrence of Refractory Coat Oven Dry, only cores with at least i coats are included. The machine property **Oven Type** determines whether the number-of-loads calculation is area based (**Conveyor**) or volume based (**Rack**). See the formulas [Number of Oven Cycles Required Area Based](#) and [Number of Oven Cycles Required Volume Based](#), below.

Number of Oven Cycles Required Area Based = Total Mold and Core Projected Area / (Machine Bed Area * Available Oven Spatial Factor)

For Conveyor machines, the number of required oven cycles depends on the following:

- Total core projected area: this is the total surface area (on the conveyor) occupied by one part's oven-dried cores. For each core, the surface area occupied is assumed to be the projected area of the core's bounding box. If this is the i^{th} occurrence of Refractory Coat Oven Dry, only cores with at least i coats are included.

The cost model assumes that each core lies on the conveyor in the "flattest" orientation (with the shortest dimension vertical). So the projected area of a core's bounding box is the product of the longest two bounding box dimensions (see [Core Bounding Box Dimensions](#)).

- Machine bed area (product of the machine properties **Bed Length** and **Bed Width**)
- Available oven spatial factor: the cost model assumes that the cores in one machine load are arranged so that the total projected area of their bounding boxes is this fraction of machine bed area. The fraction is specified by the square of the cost model variable **defaultRefractoryCoatOvenSpaceAvailableFactor** (0.8 in starting point VPEs). (The cost model variable specifies a linear allowance, so the area allowance is the square of this.)

Number of Oven Cycles Required Volume Based Total Mold and Core Volume / (Machine Bed Volume * Available Oven Spatial Factor)

For Rack machines, the number of required oven cycles depends on the following:

- Total core volume: this is the total volume occupied by one part's oven-dried cores. For each core, this is the volume of the core's bounding box (see [Core Bounding Box Dimensions](#)).
- Machine bed volume (product of the machine properties **Bed Length**, **Bed Width**, and **Bed Height**)
- Available oven spatial factor: the cost model assumes that the cores in one machine load are arranged so that their bounding boxes occupy this fraction of machine volume. The fraction is specified by the cube of the cost model variable **defaultRefractoryCoatOvenSpaceAvailableFactor** (0.8 in starting point VPEs). (The cost model variable specifies a linear allowance, so the volume allowance is the cube of this.)

Core Bounding Box Dimensions

Core bounding box dimensions are specified by the following geometric properties of the cored GCD:

- Simple Hole:
 - **Diameter** (used for two of the three bounding box dimensions)
 - **Length**
- Multistep Hole or Ringed Hole:
 - **Total Length**
 - **Max Diameter** (used for two of the three bounding box dimensions)
- Void or Combo Void:
 - **Box Length**
 - **Box Width**
 - **Box Height**

Refractory Coat Air Dry for Die Casting

Coated cores that are too large to fit in any oven are assumed to be air dried. So this process is included when at least one coated core is too large to fit in any oven (see [Refractory Coat Oven Dry Machine Selection](#)).

This process occurs multiple times in a costing when at least one air-dried item receives multiple coats (see [Number of Coating Applications](#)). The number of times the process occurs is the number, N , of coats applied to that air-dried core that has the greatest number of coats. There are N instances of the air-dry process, where the i^{th} instance includes the core that receive at least i coating applications, for all i between 1 and N .

Cycle Time = Air Dry and Cool Time * Cycle Time Adjustment Factor

Cycle time is the product of the following:

- Air dry and cool time: this is the time required to dry the part's cores, after one coating application. By default, it is specified by the cost model variable **defaultAirDryAndCoolTime** (60 minutes in starting point VPEs). Users can override the default of a per-part basis with the setup option [Air Dry and Cool Time](#).
- Cycle time adjustment factor: specified by the cost model variable **cycleTimeAdjustmentFactor**; 1 in aPriori starting point VPEs.

Required Clamp Force

Required clamp force affects machine selection for die casting (see [Machine Feasibility and Selection for Die Casting](#)). It is calculated with the following formula:

$$\text{Required Clamp Force} = ((\text{Parting Line Projected Area} * \text{Number of Cavities}) + \text{Runner Area}) * \text{Material Clamp Force} * \text{Clamp Safety Factor} / 1000$$

Required clamp force depends on the following factors:

- Parting line projected area (obtained from GCD extraction)
- Number of cavities (see [Number of Mold Cavities for Die Casting](#))
- Runner area (see formula below)
- Clamping force associated with the material
- Clamp safety factor

$$\text{Runner Area} = \text{Number of Cavities} * (\text{Part Length} + \text{Part Width}) * (\text{Maximum Wall Thickness} + 1.5)$$

Runner area depends on the following:

- Number of cavities (see [Number of Mold Cavities for Die Casting](#))
- Part dimensions (obtained from GCD extraction)
- Maximum wall thickness (obtained from GCD extraction)

Coremaking for Die Casting

The cost model for this process relies on the formulas below.

$$\text{Expendable Tooling Cost} = \text{Sand Cost} / \text{Final Yield}$$

Expendable tooling cost is a function of the following:

- Sand Cost (aggregated from child operations; based on core volume together with new sand cost per unit mass, sand disposal cost per unit mass, and sand density, listed in the **sand** lookup table)
- Final yield (see [Yields For Die Casting](#))

Cycle Time = Process Time * Cycle Time Adjustment Factor

Cycle time is the product of the following:

- Process time (sum of the cored feature cycle times--see formula below)
- Cycle time adjustment factor: specified by the cost model variable **cycleTimeAdjustmentFactor**; 1 in aPriori starting point VPEs.

Cycle Time Per Cored Feature = Machine Base Cycle Time / Number of Corebox Cavities

Cycle time per cored feature is a function of the following:

- Machine base cycle time (specified as a machine property)
- Number of corebox cavities (see below)
- Machine process yield (specified as a machine property)

If the process setup option **Corebox Cavity Calculation Mode** set to **Opportunistic** (the default setting in starting point VPEs), the number of corebox cavities is the maximum number of cavities that will fit along the length direction of the coremaking machine. This depends on the following:

- Core feature dimensions (obtained from GCD extraction)
- Machine variables that specify maximum corebox dimensions
- Plant variables **coreboxLengthAllowance** and **lengthCorePrint**

If the setup option is set to **Single Cavity**, the number of corebox cavities is 1. The default setup option setting is specified by the cost model variable **coreboxCalcMode** (**Opportunistic** in starting point VPEs).

Number of Mold Cavities for Die Casting

The number of mold cavities defaults to the value of the cost model variable **defaultNumCavities** or **defaultNumCavitiesGravityDieCasting** (1 in starting point VPEs).

You can override the default and specify the number of cavities, or request calculation of the number of cavities that minimizes total cost. You can also direct aPriori to calculate the number of cavities required to meet the annual production volume specified in the Production Scenario tab of the Cost Guide. See [User Inputs for Die Casting](#).

If the user overrides the default, the actual number of cavities is the smallest number of cavities that (i) uses one of the layouts in the table below and (ii) equals or exceeds the number specified by the user or calculated by aPriori. The layouts minimize area for a given number of cavities, and are specified in the lookup table **layoutNumCav**.

Cavities Length Wise	Cavities Width Wise	Number Of Cavities
1	1	1
2	1	2
2	2	4

4	2	8
4	4	16
6	4	24
8	4	32
10	4	40
8	6	48
14	4	56
8	8	64
12	6	72
10	8	80
12	8	96

In order to calculate the number of cavities that minimizes total cost, the cost engine performs a full costing using each layout in the table above, and then chooses the one with the lowest cost.

Calculation of the number of cavities required to meet the specified production volume assumes round-the-clock production and depends on the following:

- Required annual volume
- Plant efficiency
- An estimate of cycle time

Tooling Cost for Die Casting

Tooling cost appears as **Hard Tooling Cost** in the cost taxonomy under **Capital Costs**. It includes cost for the following:

- Materials
- Labor
- Miscellaneous services
- Markup
- SG&A

A number of user setup options affect tooling costs—see [User Inputs for Die Casting](#).

Tool Life for Die Casting

The tooling model estimates the number of parts that can be produced with a given tool before it wears to the point that it needs to be replaced. Based on that estimate, the cost model determines the number of tools required to manufacture the production volume specified in the Production Scenario tab of the Cost Guide, and accounts for that number of tools in total hard tooling cost.

Tool-life estimation is based on part material, and adjusted for tool material and tool coating type, as follows:

- 1 To determine an unadjusted value for the number of shots that can be endured by a single tool, the cost model looks up this number by part material in the lookup table **tblToolLife**.

tblToolLife	
Material Type	Num Shots Per Tool
Aluminum	110,000.00
Aluminum Bronze	110,000.00
Brass	15,000.00
Bronze	15,000.00
Copper	15,000.00
Lead	2,500,000.00
Magnesium	160,000.00
Manganese Bronze	15,000.00
Silicon Brass	15,000.00
Zinc	900,000.00
Zinc-Aluminum	900,000.00

- This value is then multiplied by the number of mold cavities (see **Number of Mold Cavities for Die Casting**), yielding the unadjusted number of parts that can be produced by a single mold.
- The result is then adjusted for mold material (see the setup option **Base Tool Material**) by multiplying it by the tool shop property **Tool Life Factor** for the current mold material.
- That result is then adjusted for mold coating by multiplying it by the **Tool Life Improvement Factor** looked up in the table **tblToolCoating** by coating type (see the setup option **Plating of Die Components**).

tblToolCoating		
Coating Cost Factor (USD / kg)	Coating Type	Tool Life Improvement Factor
0.00	None	1.00
1.90	Tribo-coating	1.10
2.80	Electroless Nickel	1.40
3.50	Electroless Teflon	1.70
4.10	Nitrided Steel	1.90
4.40	Electroplated Chromium	2.00
6.90	Plasma Sprayed	3.00
18.20	PVD TiN	7.20
19.10	CVC TiC	7.50
26.60	DuplexVariantic	14.40

For a given costing, either the formula Dependencies or Investment tab displays the number of tools assumed by tooling cost calculations.

Mold Material Costs for Die Casting

Mold material costs include costs for the following:

- Mold base
- Ejection system
- Cooling system
- Unscrewing mechanism (if any)

Costs for ejection and cooling systems are adjusted with a region multiplier, specified as a toolshop variable.

The mold base can be standard or custom (see Mold Construction in [User Inputs for Die Casting](#)). Standard mold base cost is calculated based on the size of the mold and the mold material. Standard mold size is based on the part dimensions, the number of cavities, and the number of required side cores.

The cost depends on size together with properties of the mold material (specified as toolshop variables):

- **Coeff A**
- **Coeff B**
- **Coeff C**
- Height Multiplier

It also includes the costs of the following:

- Mold base
- Ejector pins
- Electrodes
- Slides

Custom mold base costs include the costs of the following:

- Cavity plates
- Core plate
- Electrodes
- Ejector base
- Guide pins
- Socket head screws
- Side locks
- Leader pins
- Sprue bushings
- Sprue spreader
- Stop pins
- Support pillars
- Limit switches
- Locating rings
- Core pins
- Dowel pins

Mold Labor Costs for Die Casting

Mold labor costs include the following:

- Design cost

- CNC machining cost
- General machining cost
- EDM machining cost
- Bench finishing
- Mold assembly
- Spotting
- Inspection
- Cutter paths design
- Water lines drilling

Labor costs are affected by tolerance settings, among other setup options—see [User Inputs for Die Casting](#).

Mold Services Costs

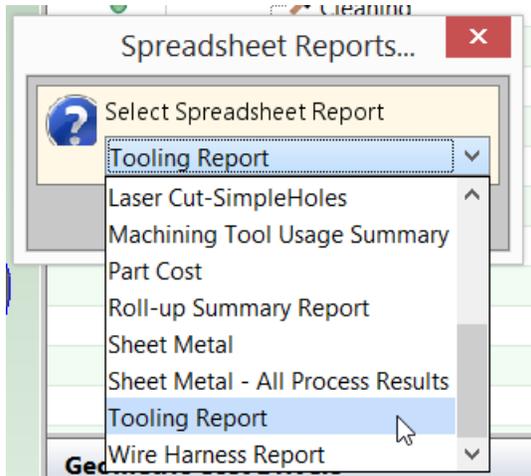
Costs for miscellaneous tool services includes costs for all the following that are enabled (see [User Inputs for Die Casting](#)):

- Stress relief
- Heat treatment
- Texturing
- Plating
- Freight
- Import Duty
- Tryouts

Costs for texturing and plating are adjusted with a region multiplier, specified as a toolshop variable.

Tooling Reports

The Tooling Spreadsheet Report contains a breakdown of tooling costs. Select Spreadsheet Reports from the Reports menu, and then select Tooling Report from the dropdown menu:



The report includes the following categories:

CNC Machining Cost

CNC Machining hours - actions

CNC Machining hours - EDM electrodes

CNC Machining hours - core and cavity

CNC Programming Cost

CNC Programming hours - actions

CNC Programming hours - EDM electrodes

CNC Programming hours - core and cavity

Design Cost

Design Time - overall mold flow/CAD hours

Design Time - parting surface

Finishing, Polishing Cost

Finishing, Polishing hours

Gun Drilling Water Lines Cost

Gun Drilling Water Lines hours

Inspection/CMM Cost

Inspection/CMM hours

Spotting Cost

Spotting hours - actions

Spotting hours - parting line

Material Cost - Mold Base Cost
Material Cost - Misc. Mold Components
Material Cost - Cooling System
Material Cost - Ejector Box
Material Cost - Unscrewing Mechanisms
Misc. Costs - Heat Treatment
Misc. Costs - Plating
Misc. Costs - Stress Relief
Misc. Costs - Texturing
Misc Cost - Tooling Freight
Misc. Costs - Tooling Import Duty
Misc. Costs - Tryout Cost
Misc. Time - Tryout Time
Mold Area
Mold Assembly Cost
Mold Assembly hours
Mold Base Weight
Mold Size - Cavity plate height
Mold Size - Core plate height
Mold Size - Length
Mold Size - Width
Number of Cavities
Number of Slides per Cavity - Large Size
Number of Slides per Cavity - Medium Size
Number of Slides per Cavity - Small Size
Tooling Cost - Total for all Slides
Number of Unscrewing Mandrels per Cavity
Other Machining Cost - Facing, Drill/Tap, etc
Other Machining - Facing, Drill/Tap, etc
Total Tool Labor Cost
Total Tool Markup/Profit
Total Tool Material Cost
Total Tool Misc. Service Costs
Total Tool SG&A Cost
TOTAL TOOLING COST

User Inputs for Die Casting

You can control the values listed below by modifying **Process Setup Options**, plant variables, or toolshop variables.

To access **Process Setup Options** for a given process, right click the process in the Manufacturing Process pane, and select **Process Setup Options** from the context menu.

This section has the following subsections:

- Casting - Die Node Inputs
- Melting Process Inputs
- High Pressure and Gravity Die Casting Process Inputs
- Refractory Coating Process Inputs for Die Casting
- Finishing Process Input

Casting - Die Node Inputs

The Casting-Die node provides the following process setup option:

- **Corebox Cavity Calculation Mode:** This PSO is defined on the Casting node. If this is set to **Opportunistic** (the default setting in starting point VPEs), the number of corebox cavities is the maximum number of cavities that will fit along the length direction of the coremaking machine. If set to **Single Cavity**, the number of corebox cavities is 1. The default setting is specified by the cost model variable **coreboxCalcMode** (**Opportunistic** in starting point VPEs). See [Sand Casting Tooling—Core Making](#) for more information.
- **Draft Angle Check:** Draft check settings allow you to determine whether aPiori checks for drafts
- **Minimum Wall Thickness Check:** This option allows you to determine whether aPiori checks minimum wall thickness feasibility.
- **Maximum Wall Thickness Check:** This option allows you to determine whether aPiori checks maximum wall thickness feasibility.
- **Minimum Hole Diameter Check:** This option allows you to determine whether aPiori checks for hole diameters that are too small to cast.
- **Maximum Hole Depth Check:** This option allows you to determine whether aPiori checks for holes that are too deep to cast.
- **Minimum Edge Radius Check:** This option allows you to determine whether aPiori checks for edge radii that are too small to cast.

Melting Process Inputs

Melting provides the following process setup options:

- **Mass Waste:** Mass waste is the mass of that portion of the pouring volume contained in the feeder system (runners, risers, etc.). By default, it is calculated as described in [Material Cost and Utilization for Die Casting](#) (see the formula Mass Waste). You can override the default by entering a value in kilograms. Note that the override affects only taxonomy calculations, and has no effect on machine selection.

- **Mass Loss:** Mass loss is the pouring mass per part of metal that is oxidized or spilled during melting and cannot be re-melted. By default, it is calculated as described in [Material Cost and Utilization for Die Casting](#) (see the formula Mass Loss). You can override the default by entering a value in kilograms. Note that the override affects only taxonomy calculations, and has no effect on machine selection.
- **Metal Additive Type:** This PSO allows you to select from among the additive types specified in the lookup table **tblMetalAdditives**. The default additive type is named **Default** in the lookup table.
- **Metal Additive Rate:** This PSO allows you to enter the additive cost per unit mass. The default additive rate is looked up by additive type in the lookup table **tblMetalAdditives**. The default additive type is named **Default** in the lookup table, with a rate of \$0.22 per kg in starting point VPEs. See also the **PSO Metal Additive Type**.
- **Material Remelt Allowance Percentage:** This PSO allows you enter the fraction of waste that can be remelted. See [Material Cost and Utilization for Die Casting](#). By default this is specified by the cost model variable **defaultRemeltAllowancePM** (1 in starting point VPEs).

High Pressure and Gravity Die Casting Process Inputs

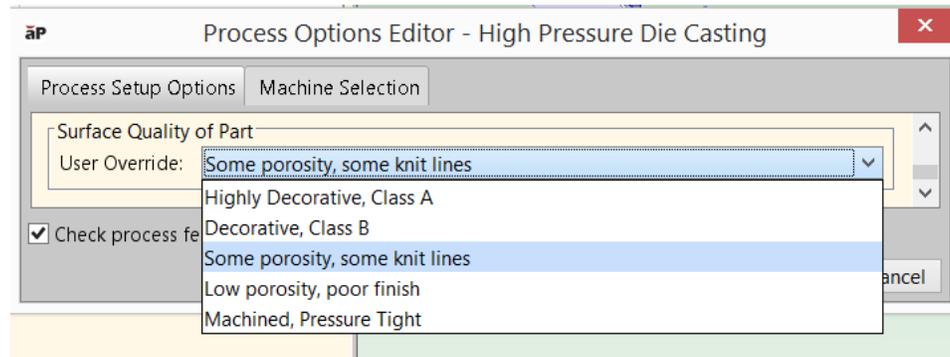
High Pressure Die Casting provides the following process setup options:

- **Number of cavities:** By default, the number of mold cavities is the maximum number of cavities that can fit on the selected machine. With this option, you can override the default and specify the number of cavities, or direct aPriori to calculate the number of cavities that minimizes total cost. See [Number of Mold Cavities for Die Casting](#) for more information.
- **Mold Material:** The default mold material is specified by the toolshop variable Default Tool Material Name (in starting point VPEs, this is P20 Tool Steel for High Pressure Die Casting and 4140 Tool Steel for Gravity Die Casting). To override the default, select a material from the dropdown list. See also [Tooling for Die Casting](#).
- **Tolerances:** By default, the mold is assumed to accommodate a part with medium tolerance (+/- 0.005mm). To override the default, select high (+/- 0.002mm) or low (+/-0.01mm) tolerance from the dropdown list. This tolerance setting affects tooling labor costs. See also [Tooling Cost for Die Casting](#).
- **Maximum Wall Thickness:** By default, maximum wall thickness is determined by geometry extraction on the CAD model. Specify a value to override the default. Maximum wall thickness affects cooling time. See [High Pressure Die Casting and Gravity Die Casting Process Formulas](#).
- **SG&A Rate:** By default, the assumed percentage of tooling costs attributable to sales, general, and administrative costs is specified by the toolshop variable SG&A Rate (9.91% in starting point VPEs). Enter a value between 0 and 100 to override the default. This setting affects tooling costs—see [Tooling Cost for Die Casting](#).
- **Margin Rate:** By default, the assumed markup for tooling costs is specified by the toolshop variable Mark Up Rate (6% in starting point VPEs). Enter a value between 0 and 100 to override the default. This setting affects tooling costs—see [Tooling Cost for Die Casting](#).

- Stress Relief Mold: By default, costs for stress relief are not included in mold costs. To override the default, select Yes from the dropdown list. This setting affects tooling services costs—see [Tooling Cost for Die Casting](#).
- Mold Base Size – Length: By default, mold dimensions are calculated from part dimensions, constrained by certain toolshop variables. To override the default, enter a value. This setting affects tooling material costs—see [Tooling Cost for Die Casting](#).
- Mold Base Size – Width: By default, mold dimensions are calculated from part dimensions, constrained by certain toolshop variables. To override the default, enter a value. This setting affects tooling material costs—see [Tooling Cost for Die Casting](#).
- Core Plate Height: By default, the core plate thickness prior to machining is calculated based on part height and values looked up in the table tblCorePlateDepthBorder. To override the default, enter a value. This setting affects tooling material costs—see [Tooling Cost for Die Casting](#).
- Cavity Plate Height: By default, the core plate thickness prior to machining is calculated based on part height and values looked up in the table tblCorePlateDepthBorder. To override the default, enter a value. This setting affects tooling material costs—see [Tooling Cost for Die Casting](#).
- Number of Small Slides or Side Cores: By default, this is determined by geometry extraction and the value of the cost model variable smallSlideBundleWidthThreshold. To override the default, enter a value less than or equal to 128. This setting affects tooling material costs—see [Tooling Cost for Die Casting](#).
- Number of Medium Slides or Side Cores: By default, this is determined by geometry extraction and the values of the cost model variables smallSlideBundleWidthThreshold and mediumSlideBundleWidthThreshold. To override the default, enter a value less than or equal to 128. This setting affects tooling costs—see [Tooling Cost for Die Casting](#).
- Number of Large Slides or Side Cores: By default, this is determined by geometry extraction and the value of the cost model variable mediumSlideBundleWidthThreshold. To override the default, enter a value less than or equal to 128. This setting affects tooling costs—see [Tooling Cost for Die Casting](#).
- Heat Treating of Mold: By default, costs for heat treatment are not included in mold costs. To override the default, select Yes from the dropdown list. This setting affects tooling services costs—see [Tooling Cost for Die Casting](#).
- Cavity Texture: By default, costs for texturing are not included in mold costs. To override the default, select a texture type (fine-shallow, moderate-medium, or coarse-deep) from the dropdown list. This setting affects tooling costs—see [Tooling Cost for Die Casting](#).
- Plating of the Mold: By default, costs for plating are not included in mold costs. To override the default, select a plating type (Nickel, Nitride, Chrome, Teflon, or Tribo-Coating) from the dropdown list. This setting affects tooling services costs—see [Tooling Cost for Die Casting](#).
- Freight Rate: By default, tooling freight costs are specified by the tool shop variable Freight Rate (0 in starting point VPEs). To override the default, enter a cost per unit mass.

- **Select Ejector Box Material:** The default ejector box material is specified by the toolshop variable Default Tool Material Name (in starting point VPEs, this is P20 Tool Steel for High Pressure Die Casting and 4140 Tool Steel for Gravity Die Casting). To override the default, select a material from the dropdown list. See also [Tooling for Die Casting](#).
- **ImportDuty Rate:** By default, tooling import duty costs are specified by the tool shop variable Duty Rate (0 in starting point VPEs). To override the default, enter a cost per unit mass.
- **Mold Construction:** Mold bases can be either standard or custom—see [Tooling Cost for Die Casting](#). The default is specified by the cost model variable defaultMoldConstruction (standard, in starting point VPEs). To override the default, select a value from the dropdown list. This setting affects tooling material costs.
- **Parting Line Complexity:** By default this is determined by geometry extraction. To override the default, select a value from the dropdown list. This setting affects tooling labor costs—see [Tooling Cost for Die Casting](#).
- **Select Material for the Slides:** The default slide material is specified by the toolshop variable Default Tool Material Name (in starting point VPEs, this is P20 Tool Steel for High Pressure Die Casting and 4140 Tool Steel for Gravity Die Casting). To override the default, select a material from the dropdown list. See also [Tooling for Die Casting](#).
- **Cavity Finish:** With High Pressure Die Casting, by default, costs for a finish on the mold cavity are not included in mold costs. For Gravity Die Casting, costs for a Grain finish on the mold cavity are included. To override the default, select a finish type (None, Stone, Grain, or Lens) from the dropdown list. This setting affects tooling services costs—see [Tooling Cost for Die Casting](#).
- **Select EDM Electrode Material:** The default electrode material is Carbon. To override the default, select a material from the dropdown list (Carbon or Copper). This setting affects tooling material costs—see [Tooling Cost for Die Casting](#).
- **Number of Core Pins:** By default, the number of core pins is calculated by aPriori. To override the default, specify a number less than or equal to 128. This setting affects tooling costs—see [Tooling Cost for Die Casting](#).
- **Number of Unscrewing Mechanisms:** By default, the number of unscrewing mechanisms is calculated by aPriori. To override the default, specify a number less than or equal to 64. This setting affects tooling costs—see [Tooling Cost for Die Casting](#).
- **Number of Runners:** By default the gating system is assumed to have a single runner, if the mold has a single cavity; for molds with multiple cavities, the default number of runners is half the number of cavities (rounded up to the nearest whole number of runners). Users can specify the number of runners with this option. See the formulas for Runner Volume and Runner Area in [Gating System Formulas](#).
- **Number of Ingates:** Gravity Die Casting only. By default, there is one ingate for every 6 inches of part length, in starting point VPEs. This distance is specified by the cost model variable **ingateGap**. This is the maximum distance between ingates for a given cavity. With this setup option, you can override the default, and specify the number of ingates explicitly.
- **Surface Quality of Part:** High Pressure Die Casting only. By default, part surface quality is 3 (**Some porosity, some knit lines**), but users can override the default with

this option. Part surface quality affects calculations related to the gating system--see the formulas for Ingate Area and Inject Time in [Gating System Formulas](#).



- **Part Eject Method:** By default in starting point VPEs, the part eject method is **Gravity**. You can customize the default with the cost model variable **gravityEject**. You can override the default on a part-by-part basis with this setup option. Specify **Gravity** or **Robotic**. The eject method affects part removal time, as well as mold open and close time. See [High Pressure Die Casting and Gravity Die Casting Process Formulas](#).

Trim Process Inputs

The Trim process provides the following process setup options:

Base Tool Material

This is used to determine tool plating costs. By default, base tool material is S7. To specify base tool material explicitly, select one of the following options:

- D2
- A2
- S7

Width of Addendum Added to Die Shoe [per side]

An offset to be added all around the die shoe. You can enter a non-zero value in order to adjust the length and width die shoe dimensions. Higher values increase die cost. Select one of the following options:

- No Addendum: this is the default.
- User Override: enter a value greater than or equal to 0.

Part Height Allowance

This setup option specifies the difference between the part height and the height of the post component of the die. The default **Part Height Allowance** is specified by the cost model variable **partHeightAllowance** (12.7mm in starting point VPEs). Note that the post height is constrained by the value of [Minimum Part Height Plus Allowance](#). That is, the post height is either the sum of the part height and **Part Height Allowance**, or the value specified by [Minimum Part Height Plus Allowance](#), whichever is greater.

Post height affects die height. Die height (which affects tooling cost and machine selection) is the sum of the following:

- Product of post height and [Post Height Multiplier](#)

- Die allowance gap (specified by the cost model variable **dieAllowanceGap**—25.4mm in starting point VPEs)
- Lower die shoe height (selected from standard shoe sizes based on part and addendum size)
- Upper die shoe height (selected from standard shoe sizes based on part and addendum size)

Select one of the following:

- Default: specified by the cost model variable **partHeightAllowance** (12.7mm in starting point VPEs)
- User Override: enter a value.

Minimum Part Height Plus Allowance

This setup option constrains the height of the die post. The post height is either the sum of part height and [Part Height Allowance](#), or the value specified by this option, whichever is greater. Select one of the following:

- Default: specified by the cost model variable **minimumPartHeightPlusAllowance** (50.8mm in starting point VPEs)
- User Override: Enter a value greater than or equal to 0.

Post Height Multiplier

Specifies the number of posts that contribute to the die height. Die height, which affects tooling cost and machine selection, is the sum of the following:

- Product of post height (see [Part Height Allowance](#)) and Post Height Multiplier
- Die allowance gap (specified by the cost model variable **dieAllowanceGap**—25.4mm in starting point VPEs)
- Lower die shoe height (selected from standard shoe sizes based on part and addendum size)
- Upper die shoe height (selected from standard shoe sizes based on part and addendum size)

Select one of the following:

- Default: specified by the cost model variable **postHeightMultiplier** (1 in starting point VPEs)
- User Override: enter a value greater than or equal to 1.

Freight Cost

Freight cost applied to tooling defaults to 0. To explicitly specify a tooling freight charge, enter a value greater than or equal to 0.

Total Gage Cost

Total gage cost applied to tooling defaults to 0. To explicitly specify a tooling gage cost, enter a value greater than or equal to 0.

Heat Treat of Die Components

Die components are heat treated by default. This option provides a dropdown list with the following items:

- Yes: perform heat treatment.
- No: do not perform heat treatment.

To override heat treatment, select **No** from the dropdown list.

Plating of Die Components

By default, the material used for die plating is specified by the cost model variable **highStrengthMatlToolingCoatingType** (DuplexVariantic in starting point VPEs).

To specify plating material explicitly, select one of the following options:

- None
- Nickel
- Chrome
- Nitride
- Teflon
- Tribo-Coating
- DuplexVariantic
- CVD

Total Welding Cost

Total welding cost applied to tooling defaults to 0. To explicitly specify a tooling welding cost, enter a value greater than or equal to 0.

Total Carrying Cost

This is the cost for holding the completed tool in inventory prior to shipping. Total carrying cost applied to tooling defaults to 0. To explicitly specify a tooling carrying cost, enter a value greater than or equal to 0.

Refractory Coating Process Inputs for Die Casting

The Core Refractory Coating operation (under the Core Refractory Coat process) provides the following options:

- Refractory Coating Included
- Application Method
- Number of Coating Applications
- Number of Operators
- Refractory Coating Preparation Time

The processes Refractory Coat Oven Dry and Refractory Coat Air Dry provide the following options:

- Oven Dry and Cool Time
- Air Dry and Cool Time

- Setup Time for the Oven
- Setup Time for Air Drying
- Labor Handling Number of Operators

Refractory Coating Included

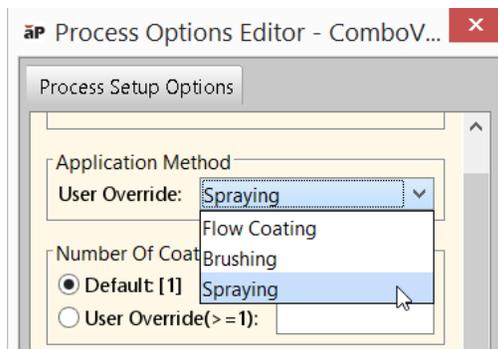
(Provided by the Core Refractory Coating operations.)

By default in starting point VPEs, cores are assumed to be coated. Administrators can customize the default with the cost model variable **defaultCoreRefractoryCoatingInclusion**. Users can override the default on a per-cored-GCD basis with this setup option.

See also [Die Casting Process-level Routing](#).

Application Method

(Provided by the Core Refractory Coating operations.)



By default in starting point VPEs, refractory coating is *sprayed* onto cores. Administrators can customize the default with the cost model variable **defaultCoreRefractoryCoatingMethod**. With this setup option, users can override the default on a per-cored-GCD basis.

Application method drives cycle time, which depends on [Number of Coating Applications](#), core surface area, and application rate. Application rate is looked up by application method in the lookup table **tblRefractoryCoating**.

Application Method	Application Rate (m ² / min)	Average Output Volume (L / min)
Brushing	0.28	2.00
Flow Coating	3.85	25.00
Spraying	5.13	6.00

Application method also drives coating material costs, which is calculated based on output volume per unit time (looked up in **tblRefractoryCoating**) and cost per unit volume (specified by the tool shop variable **Refractory Coating Cost**).

See [Core Refractory Coating for Die Casting](#) for more information.

Number of Coating Applications

(Provided by the Core Refractory Coating operations.)

By default, the number of coating applications for cores is specified by the cost model variable **defaultNumCoreRefractoryCoatingApplications** (1 in starting point VPEs). With this setup option, users can override the default on a per-cored-GCD basis.

This setup option helps determine the number of occurrences of the Core Refractory Coating process. Note that cores are assumed to be dried after each application.

See [Core Refractory Coating for Die Casting](#) for more information.

Number of Operators

(Provided by the Core Refractory Coating operations.)

By default, the number of operators coating the core for a given GCD is specified by the cost model variable **defaultCoreRefractoryCoatingNumOperators**. (1 in starting point VPEs). Users can override the default on a per-part basis with this setup option. See also [Core Refractory Coating for Die Casting](#).

Refractory Coating Preparation Time

(Provided by the Core Refractory Coating operations.)

This is the time to perform batch setup for the specified GCD's cores, that is, the time to prepare and mix the coating for the current GCD's cores for one production batch of parts. By default, this is specified by the cost model variable **defaultRefractoryCoatingCorePreparationTime** (0.25 hours in starting point VPEs). (The use of a slurry mix is assumed by default in starting point VPEs.) With this setup option, users can override the default on a per-cored-GCD basis.

Oven Dry and Cool Time

(Provided by the Refractory Coat Oven Dry process.)

This is the time to oven dry and cool one machine load of cores. By default, it is specified by the cost model variable **defaultOvenDryAndCoolTime** (19 minutes in starting point VPEs). Users can override the default with this setup option.

See [Refractory Coat Oven Dry for Die Casting](#) for more information.

Air Dry and Cool Time

(Provided by the Refractory Coat Air Dry process.)

This is the time to air dry and cool all cores belonging to one part. By default, it is specified by the cost model variable **defaultAirDryAndCoolTime** (60 minutes in starting point VPEs). Users can override the default with this setup option.

See [Refractory Coat Air Dry for Sand Casting](#) for more information

Setup Time for the Oven

(Provided by the Refractory Coat Oven Dry process.)

This is the time to set up the oven for the cores in one production batch of parts. If any cores have a second coating then the drying setup is doubled. By default, this is specified by the cost model variable **defaultRefractoryCoatingOvenDryPreparationTime** (0.25 hours in starting point VPEs). With this setup option, users can override the default on a per-part basis.

Setup Time for Air Drying

(Provided by the Refractory Coat Air Dry process.)

This is the time to set up the floorspace for the cores in one production batch parts. If any cores have a second coating, the drying setup is doubled. By default, this is specified by the cost model variable **defaultRefractoryCoatingAirDryPreparationTime** (0.25 hours in starting point VPEs). With this setup option, users can override the default on a per-part basis.

Labor Handling Number of Operators

(Provided by the Refractory Coat Oven Dry and Refractory Coat Air Dry processes.)

This is the number of operators that are assumed to load and unload cores for drying. By default, it is specified by the following cost model variables:

- **defaultRefractoryAirDryNumberLaborers** (1 in starting point VPEs)
- **defaultRefractoryOvenDryNumberLaborers** (1 in starting point VPEs)

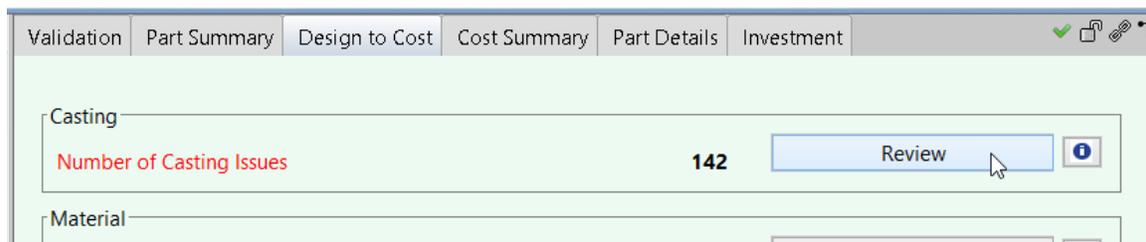
Finishing Process Input

The Finishing process provides the following setup option:

- **Percent Parting Line to Grind:** By default, the Finishing process grinds all of the parting line. To override the default, specify a percentage to grind. See also [Finishing Formulas for Die Casting](#).

Design-to-cost Configuration for Die Casting

This section covers configuring Design to Cost for the Casting—Die and Casting—Sand process groups. You can configure thresholds that help determine what casting issues, thickness violations, and tolerance-driven Machining operations are referenced in the Design to Cost tab.



The following sections cover lookup tables that specify thresholds related to Casting Issues (Material issues, Draft Issues, and Radius Issues):

- **Material Issues: Wall Thickness Thresholds**
- **Draft Issues: Draft Angle Threshold**
- **Radius Issues: Edge Radius Thresholds**
- **Proximity Issues: Hole Proximity Issues**
- **Hole Issues: Maximum Hole Depth**

- Hole Issues: Minimum Hole Diameter

A lookup table related to tolerance and roughness thresholds is covered in [Tolerance Grade and Roughness Ranges](#).

Tolerances and Finishing Operations		
GCDs with tolerances	0	Review 
Driving machining	0	
Driving specialized finishing	0	

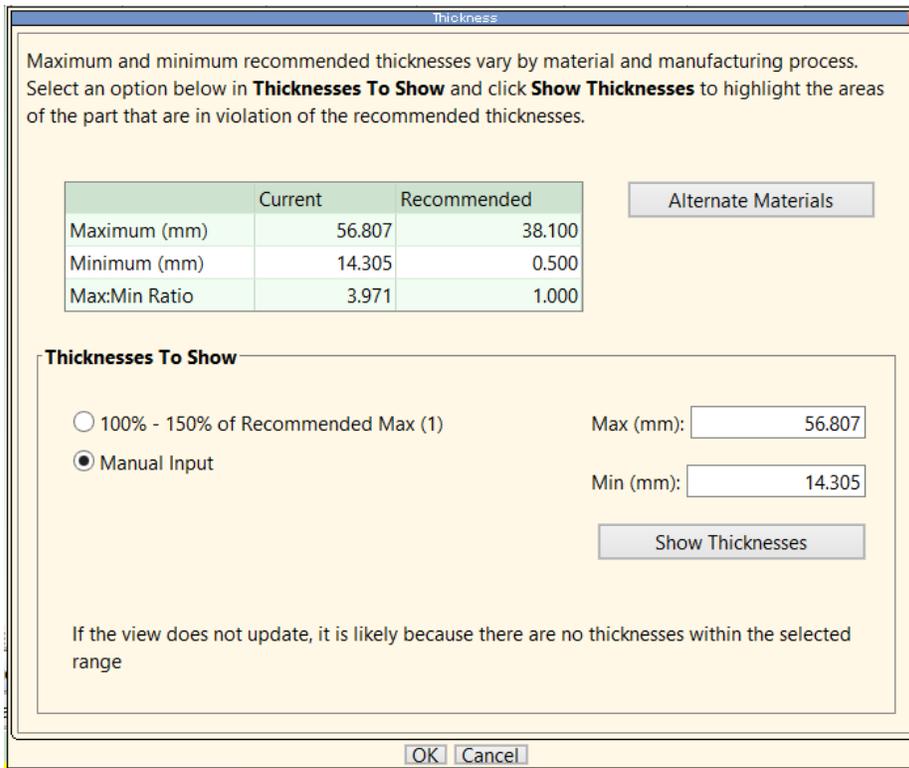
Material Issues: Wall Thickness Thresholds

The lookup table **tblWallThickness** specifies the recommended minimum and maximum wall thickness for each process and material.

tblWallThickness			
Material Type	Maximum Wall Thickness (mm)	Minimum Wall Thickness (mm)	Process Name
Aluminum	38.10	0.50	High Pressure Die Casting
Aluminum	50.50	2.00	Gravity Die Casting
Aluminum	1,016.00	3.00	Sand Casting
Aluminum Bronze	38.10	1.00	High Pressure Die Casting
Aluminum Bronze	50.50	3.00	Gravity Die Casting
Aluminum Bronze	1,016.00	3.00	Sand Casting
Brass	38.10	1.00	High Pressure Die Casting
Brass	50.50	3.00	Gravity Die Casting
Brass	1,016.00	2.30	Sand Casting
Bronze	38.10	1.00	High Pressure Die Casting
Bronze	50.50	3.00	Gravity Die Casting
Bronze	1,016.00	2.30	Sand Casting

If the thickness of some portion of a part’s wall falls outside of this range, a corresponding Material Issue is listed under Casting issues.

In addition, the Thickness panel of the Design to Cost tab displays the Recommended Maximum and Minimum thickness.



Draft Issues: Draft Angle Thresholds

The lookup table `tblDraftAngle` specifies the minimum recommended draft angle for each material and process.

Material Type	Min Draft Angle (deg)	Process Name
Aluminum	0.25	High Pressure Die Casting
Aluminum	0.50	Gravity Die Casting
Aluminum	0.50	Sand Casting
Aluminum Bronze	0.25	High Pressure Die Casting
Aluminum Bronze	0.50	Gravity Die Casting
Aluminum Bronze	0.50	Sand Casting
Brass	0.50	Gravity Die Casting
Brass	0.50	Sand Casting
Brass	0.70	High Pressure Die Casting
Bronze	0.50	Gravity Die Casting
Bronze	0.50	Sand Casting
Bronze	0.70	High Pressure Die Casting
Copper	0.50	Gravity Die Casting

If the draft angle of some feature is less than the relevant minimum, a corresponding Draft Issue is listed under Casting issues.

Casting Issues

- GCDs listed below failed the casting process for various reasons. Click on the GCD in the right hand table to see the specific failure and view the GCD in the viewer.
- To allow violations of feature specific rules, click the appropriate check boxes below and click OK to recast and close the dialog

Issue Type	Count	Type	GCD	Current	Suggested
Material Issue	1	Minimum Draft Angle	PlanarFace:34	0 deg	>= 0.5 deg
Draft Issue	115	Minimum Draft Angle	PlanarFace:35	0 deg	>= 0.5 deg
Hole Issue	19	Minimum Draft Angle	PlanarFace:36	0 deg	>= 0.5 deg
		Minimum Draft Angle	PlanarFace:37	0 deg	>= 0.5 deg

Radius Issues: Edge Radius Thresholds

The lookup table **tblMinEdgeRadius** specifies the minimum recommended internal and external edge radius for each material and process.

Material Type	Min External Radii (mm)	Min Internal Radii (mm)	Process Name
Aluminum	0.30	3.00	Sand Casting
Aluminum	0.50	0.25	High Pressure Die Casting
Aluminum	6.00	2.00	Gravity Die Casting
Aluminum Bronze	0.30	3.00	Sand Casting
Aluminum Bronze	1.00	0.50	High Pressure Die Casting
Aluminum Bronze	9.00	3.00	Gravity Die Casting
Brass	0.23	2.30	Sand Casting
Brass	1.00	0.50	High Pressure Die Casting
Brass	9.00	3.00	Gravity Die Casting
Bronze	0.23	2.30	Sand Casting
Bronze	1.00	0.50	High Pressure Die Casting
Bronze	9.00	3.00	Gravity Die Casting
Copper	0.23	2.30	Sand Casting

If the radius of some edge is less than the relevant minimum, a corresponding Radius Issue is listed under Casting Issues. Note that sharp edges on the parting line are listed separately, since only those that *partially* lie on the parting line are likely to present an issue.

Proximity Issues: Hole Proximity Issues

The recommended minimum distance between a hole and another feature is one of the following (depending on the current process):

- Sand Casting: the first Minimum Wall Thickness value that appears in the lookup table **tblWallThickness** for Sand Casting and the current material type.
- Gravity Die Casting: the first Minimum Wall Thickness value that appears in the lookup table **tblWallThickness** for Gravity Die Casting and the current material type.
- High Pressure Die Casting: this value is interpolated from values in the lookup table **tblHighPressureDieCastingHoleProximity**, and is bounded above and below the largest and smallest distances in the table. The lookup is keyed by the diameter of the hole. For the minimum recommended distance between two holes, the lookup is keyed by the diameter of the larger-diameter hole.

tblHighPressureDieCastingHoleProximity		
Process Name	Hole Diameter (mm)	Minimum Distance (mm)
High Pressure Die Casting	2.00	0.41
High Pressure Die Casting	2.50	0.55
High Pressure Die Casting	3.00	0.61
High Pressure Die Casting	3.50	0.74
High Pressure Die Casting	4.00	0.86
High Pressure Die Casting	4.50	0.92
High Pressure Die Casting	5.00	0.98
High Pressure Die Casting	6.00	1.23
High Pressure Die Casting	6.30	1.23
High Pressure Die Casting	7.00	1.23
High Pressure Die Casting	8.00	1.53
High Pressure Die Casting	10.00	1.84
High Pressure Die Casting	12.00	2.15

Hole Issues: Maximum Hole Depth

The maximum recommended hole depth for a given diameter is looked up by diameter, material type, and process in the lookup table **tblMaxHoleDepth**.

tblMaxHoleDepth			
Hole Diameter (mm)	Hole Max Depth (mm)	Material Type	Process Name
2.40	2.96	Brass	High Pressure Die Casting
2.40	2.96	Bronze	High Pressure Die Casting
2.40	2.96	Copper	High Pressure Die Casting
2.40	2.96	Manganese Bronze	High Pressure Die Casting
2.40	2.96	Silicon Brass	High Pressure Die Casting
2.40	5.97	Aluminum	High Pressure Die Casting
2.40	5.97	Aluminum Bronze	High Pressure Die Casting
2.40	5.97	Magnesium	High Pressure Die Casting
2.40	7.10	Lead	High Pressure Die Casting
2.40	7.10	Zinc	High Pressure Die Casting
2.40	7.10	Zinc-Aluminum	High Pressure Die Casting
3.18	4.76	Brass	High Pressure Die Casting
3.18	4.76	Bronze	High Pressure Die Casting
3.18	4.76	Copper	High Pressure Die Casting
3.18	4.76	Manganese Bronze	High Pressure Die Casting

If the depth of some hole is greater than the relevant maximum, or if the lookup cannot be performed because the diameter is out of range for the lookup table, a corresponding Hole Issue is listed under Casting Issues.

Hole Issues: Minimum Hole Diameter

The minimum recommended hole diameter is looked up by material type and process in the lookup table **tblMinHoleDiameter**.

tblMinHoleDiameter		
Material Type	Min Hole Diameter (mm)	Process Name
Aluminum	2.40	High Pressure Die Casting
Aluminum	4.80	Gravity Die Casting
Aluminum	4.80	Sand Casting
Aluminum Bronze	2.40	High Pressure Die Casting
Aluminum Bronze	4.80	Gravity Die Casting
Aluminum Bronze	4.80	Sand Casting
Brass	4.80	Gravity Die Casting
Brass	4.80	High Pressure Die Casting
Brass	4.80	Sand Casting
Bronze	4.80	Gravity Die Casting
Bronze	4.80	High Pressure Die Casting
Bronze	4.80	Sand Casting
Copper	4.80	Gravity Die Casting

If the diameter of some hole is less than the relevant minimum, a corresponding Hole Issue is listed under Casting Issues.

Tolerance Grade and Roughness Ranges

The lookup table **tblGtolProcessCapabilities** lists the geometric tolerance grade and roughness ranges achievable by a given process for a given type of tolerance/roughness. A tolerance grade range together with a feature size determines a literal tolerance range. See the section “How aPriori calculates achievable tolerance ranges” in the *aPriori Professional User Guide*.

tblGtolProcessCapabilities					
Process	Gtol Category	Capability System	Best Achievable	Worst Achievable	Num Repetitions
3D Laser	angularity	IT	10	16	1.00
3D Laser	bendAngleTolerance	IT	10	16	1.00
3D Laser	circularity	IT	10	16	1.00
3D Laser	concentricity	IT	10	16	1.00
3D Laser	cylindricity	IT	10	16	1.00
3D Laser	diamTolerance	IT	10	16	1.00
3D Laser	flatness	IT	10	16	1.00
3D Laser	parallelism	IT	10	16	1.00
3D Laser	perpendicularity	IT	10	16	1.00
3D Laser	positionTolerance	IT	10	16	1.00

In addition to affecting cycle times of secondary machining operations, the ranges affect what operations are listed as tolerance-driven machining operations and what operations are listed as special finishing operations. See the Tolerances and Finishing Operations section of the Design to Cost tab.

7 Casting--Sand Process Group

This chapter describes the cost model for Sand Casting. Gravity Die Casting and High Pressure Die Casting are covered in [Casting--Die Process Group](#).

This chapter includes the following topics:

- Sand Casting Cost Model Overview
 - GCD Extraction for Sand Casting
 - Feasibility and Routing for Sand Casting
 - Cost Algorithms and Calculations for Sand Casting
 - User Inputs for Sand Casting
 - Process Defaults and Thresholds for Sand Casting
 - Design-to-cost Configuration for Sand Casting
-

Sand Casting Cost Model Overview

This overview section summarizes assumptions and limitations of the following aspects of the model:

- Sand Casting General Process
- Part Geometry for Sand Casting
- Materials for Sand Casting
- Machines for Sand Casting
- Tooling for Sand Casting

Sand Casting General Process

In general, casting costs are determined by aggregating material, labor, machine, and tooling costs.

aPriori represents sand casting as a process sequence that includes moldmaking and optional coremaking processes.

There are a number of alternative moldmaking processes:

- **Vertical Automatic:** Uses high volume machines such as DisaMatic and Loramendi.
- **Horizontal Automatic:** Uses high volume machines such as Hunter HMP and Roberts Sinto FBx.
- **Manual Std Moldmaking:** Appropriate for manual mold-making at low and medium production volumes. With this process, standard flasks are filled with sand, compacted, and transported (typically by conveyor) to a pouring station, and then on to a central cooling and breakout area.
- **Manual Floor Moldmaking:** Appropriate for casting large parts that require the flask to stay in place on the foundry floor. This process is used when it is not practical to move the flask. Used for large castings, the flask is built around the pattern and core boxes, and the crucible is brought to the flask for pouring. The flask then stays in place on the floor for cooling and breakout.
- **Manual Pit Moldmaking:** Appropriate for casting of very large parts in a pit. With this process, the pit serves as the drag and a wooden frame on top of the pit provides the cope and incorporates the feeder system.

There are also provides a number of alternative coremaking processes:

- **No heat required:** with these processes, the binder in the sand becomes rigid without heat. Modern core making tends to prefer no-heat processes with minimum environmental disposal problems.
 - **Isocure Gas:** popular cold box core making process introduced in 1968 by Ashland (phenolic urethane cold-box binder). The starting point cost model prefers this method. Cores can be as small as 3/8" (9.5 mm).
 - **CO2 Cured:** similar to Isocure, this process uses CO2 gas to set the binder. The process is sometimes known as Ecolotec. The starting point cost model

considers this the second choice behind Isocure. Cores can be as small as 3/8" (9.5 mm).

- No Bake: developed in the 1960s, this method uses sand mixed with a chemical binder. The mixture cures at room temperature, but curing is relatively slow. Core sizes can go down to about 3" (76.2 mm). The method is often used for large cores, especially for floor molding.
- Manual Coremaking: for very large cores. Similar to No Bake, but cores are made by hand; a vibratory table is used to compact the sand into the corebox.
- Heat required: These processes require heat for the binder in the sand to become rigid.
 - Hot Box: developed about 1953. Hot box cores use a thermoset resin and apply heat. Core sizes go down to about 2" (50.8 mm). This method is often used for large cores.
 - Oil Core: uses an oil-based binder. The core must be baked to set. Core sizes can be as small as 3/8" (9.5 mm).
 - Shell: invented in 1947 by J. Croning. With this method, sand is blown into a heated box and the sand pressing against the box sets to form a shell. The remaining sand in the center is poured out and can be reused. The result is hollow core.

For the current cost model, this method is used for cores only. The core is baked and is considered hollow. Shell cores allow excellent surface finish, but the baking is slow. Foundries sometime buy shell cores. Core sizes can be as small as 3/8" (9.5 mm).

- Stock Core: limited to Simple Hole GCDs. Stock cores are made by a relatively inexpensive extruder that extrudes a sand mixture through an extruding head. Usually, stock cores are limited to simple hole shapes with standard (stock) diameters. A stock core can be used if the hole doesn't have a draft and if the hole axis is perpendicular to the parting direction of the mold.

If you have licensed the appropriate modules, your routing can include optional machining, heat treatment, and surface treatment processes, as well as testing, inspection, and packaging processes (which are part of the process group Other Secondary Processes).

See [Feasibility and Routing for Sand Casting](#) for more information.

Part Geometry for Sand Casting

Feasible geometries for casting are limited by machine capabilities and by the selected VPE's minimum castable diameter for holes and voids.

A part is geometrically feasible for sand casting only if it satisfies the following requirements:

- The selected VPE supports machines of the required types that can accommodate the part's size and weight, as well as core sizes.

- Hole diameter and void box sizes are larger than the plant variable **minSandCastableHoleDia** for the selected VPE.

See [GCD Extraction for Sand Casting](#), [Machine Feasibility and Selection for Sand Casting](#), and [Feasibility and Routing for Sand Casting](#) for more information.

Materials for Sand Casting

Starting point VPEs include the following types of materials, among others:

- Aluminum
- Aluminum Bronze
- Ductile Iron
- Gray Iron
- Cast Steel
- Commercial Bronze
- Ductile Iron
- Free-Cutting Brass
- Lead (cast)
- Magnesium
- Manganese Bronze
- Medium-Carbon Steel
- Silicon Brass
- Stainless Steel
- Yellow Brass

See [Material Selection for Sand Casting](#) for more information. For sand casting, users can specify the unit cost of any metal additive, such as flux—see [User Inputs for Sand Casting](#).

Machines for Sand Casting

The following tables list important property value ranges of the machines supported for the various central processes:

Horizontal Automatic (Beardsley & Piper, DisaMatic, Hunter, Roberts Sinto)

Property	Low End	High End
Flask Height (mm)	254.0	584.2
Flask Length (mm)	482.6	812.8
Flask Width (mm)	355.6	762.0

Vertical Automatic (DisaMatic, Loramendi)

Property	Low End	High End
----------	---------	----------

Flask Height (mm)	199.9	400.05
Flask Length (mm)	398.78	1,100.07
Flask Width (mm)	398.78	1,199.9

Manual Std Moldmaking (Virtual)

Property	Low End	High End
Flask Height (mm)	101.6	609.6
Flask Length (mm)	305.0	1,828.8
Flask Width (mm)	304.8	1,524.0

Manual Floor Moldmaking (Virtual)

Property	Low End	High End
Flask Height (mm)	304.8	2,000.0
Flask Length (mm)	610.0	4,000.0
Flask Width (mm)	609.6	4,000.0

Manual Pit Moldmaking (Virtual)

Property	Low End	High End
Flask Height (mm)	2,489.0	5,000.0
Flask Length (mm)	4,013.0	18,000.0
Flask Width (mm)	4,013.0	9000.0

See [Machine Feasibility and Selection for Sand Casting](#) for more information.

Tooling for Sand Casting

Users can specify the number of cavities and whether or not the system should check for drafts, rounds, or the minimum thickness feasibility. Users can also specify the mold pattern material, as well as the type, unit cost, and proportion of any sand additive.

See [Tooling Cost for Sand Casting](#) and [User Inputs for Sand Casting](#) for more information.

GCD Extraction for Sand Casting

aPriori extracts the geometry of a CAD model in the form of geometric cost drivers (GCDs) that include **Surfaces**, **Holes**, **VOIDs**, and **Combo VOIDs**, as well as the **Parting Line**. As usual, there is a special GCD, **Component**, that represents the part as a whole. Following are some of the important properties of each of these GCD types:

- **Component:**
 - Volume (mm³)
 - Surface Area (mm²)
 - Length, Width, and Height (millimeters)
 - Number of Surfaces
 - Min Thickness, Max Thickness, and Avg Thickness (millimeters)
 - Length Direction, Width Direction, and Height Direction: Each of these is a unit vector, two of whose components are 0 (the other component

is 1 or -1). These vectors can be compared with the `Direction` vector of another GCD (such as a `Perimeter` or `Setup Axis`) in order to determine whether the GCD's direction is aligned with the part's length, width, or height.

- **Parting Line:**
 - `Draw Direction`
 - `Height (millimeters)`
 - `Parting Type`
 - `Projected Area (mm2)`
- **Surfaces (Curved Surface, Curved Wall, and Planar Face):**
 - `Finished Area (mm2)`
 - `Bend Diameter (millimeters)`
 - `Perimeter (millimeters)`
 - `SER Length and SER Width (smallest enclosing rectangle dimensions in millimeters)`
 - `Corner Diameter (millimeters)`
 - `Inside Diameter (millimeters)`
 - `Number of Surfaces`
 - `Fillet Min Angle and Fillet Max Angle (degrees)`
 - `Round Radius (millimeters)`
 - `Round Length (millimeters)`
- **Holes (Simple Hole, Multistep Hole):**
 - `Diameter (millimeters)`,
 - `Length and Depth (millimeters)`
 - `Volume (mm3)`
 - `Surface Area (mm2)`
 - `Maximum diameter and Minimum diameter (millimeters—for multistep holes)`
 - `Step count (for multistep holes)`
 - `Hole type (THROUGH or BLIND)`
 - `Blind, Sleeve Pin, Threaded, Countersunk, and Flanged (TRUE or FALSE)`
 - `Accessibility (THROUGH, OBSCURED, SIDE_A, SIDE_B, or UNDERCUT-- determines operation sequence and tooling requirements.)`
- **Volumes (Void, Combo Void):**
 - `Box Length, Box Width, Box Height (millimeters)`
 - `Exposed Area (mm2)`
 - `Number of Surfaces`
 - `Number of Openings`
 - `Perimeter (mm)`
 - `Surface Area (mm2)`
 - `Tool Reach (millimeters)`

- Volume (mm³)
- Maximum Tool Diameter (millimeters)
- Parting Line Draw Distance (millimeters)
- Accessibility (THROUGH, OBSCURED, SIDE_A, SIDE_B, or UNDERCUT-- determines operation sequence and tooling requirements.)

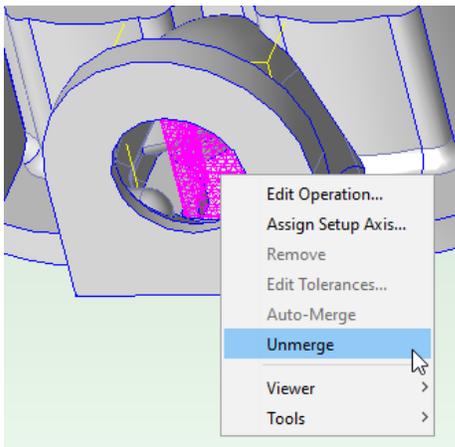
The GCD extraction algorithm creates voids when it finds a probable core because either a volume is inaccessible in the parting direction, or the flow of the metal may break away a green sand mold. Whenever a hole overlaps such a volume, a ComboVoid can result.

Each ComboVoid consists of either multiple voids or else one or more holes and one or more voids. GCD extraction algorithms presume that holes that are children of ComboVoids are manufactured mostly by the casting processes (coring, green sand, and so forth). Any machining on these holes is limited to surface finishing operations.

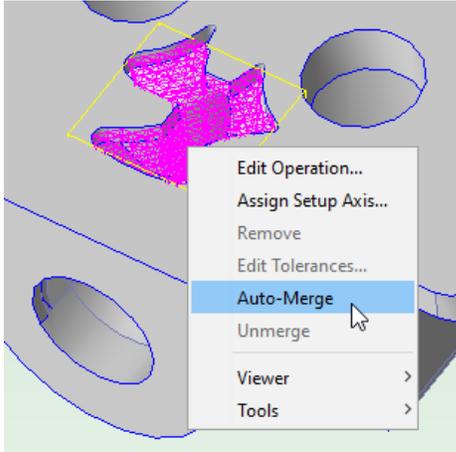
You can signal to aPriori that a hole needs to be fully machined by unmerging the hole from the ComboVoid (see below). Note that this means that the GCD extraction algorithm fills in these holes before computing thicknesses.

You can also unmerge a void from a ComboVoid, so that the void is assigned a separate operation.

Unmerge a GCD as follows: in the Geometric Cost Drivers pane, right click a GCD that is a child of a ComboVoid, and select **Unmerge**. (Alternatively, click the GCD in the Geometric Cost Drivers pane, and then right click the model in the Viewer and select **Unmerge**.)



To re-merge a GCD that previously was unmerged, right-click the GCD in the Geometric Cost Drivers pane, and select **Auto-Merge** (or click the GCD in the Geometric Cost Drivers pane, right-click the model in the Viewer, and select **Auto-Merge**).



Note that the scenario must be CAD connected in order to access these options; GCD extraction occurs as soon as **Unmerge** or **Auto-Merge** is selected.

The GCD extraction algorithm also fills in *uncastable* holes before computing thickness, based on two site variables, **minCastableHoleDiameter** and **minCastableHoleWallThickness**. Uncastable holes are those whose diameter is below **minCastableHoleDiameter** and those whose wall thickness is below **minCastableHoleWallThickness**. Uncastable holes are never included in ComboVoids. Note that VPEs may have variables with the same name as the site variables. The VPE variables change the cost model behavior but have no effect on GCD extraction.

In some rare cases the algorithm that fills in holes fails. In this case aPriori does not create a hole GCD at all.

Feasibility and Routing for Sand Casting

When you choose the Casting--Sand process group, aPriori selects process-level routings, operation-level routings, as well as machines and materials. These procedures are described in the following sections:

- Sand Casting Process-level Routing
- Sand Casting Process-level Feasibility
- Coremaking Feasibility and Routing for Sand Casting
- Sand Casting Operation-level Feasibility
- Material Selection for Sand Casting
- Machine Feasibility and Selection for Sand Casting

Sand Casting Process-level Routing

Each Sand Casting routing consists of all the following processes:

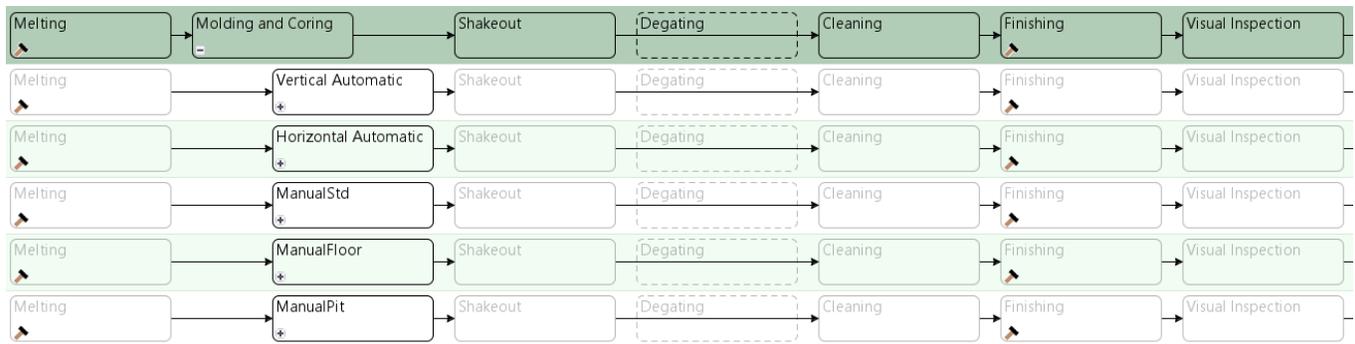
- Melting
- Molding and Coring process routing

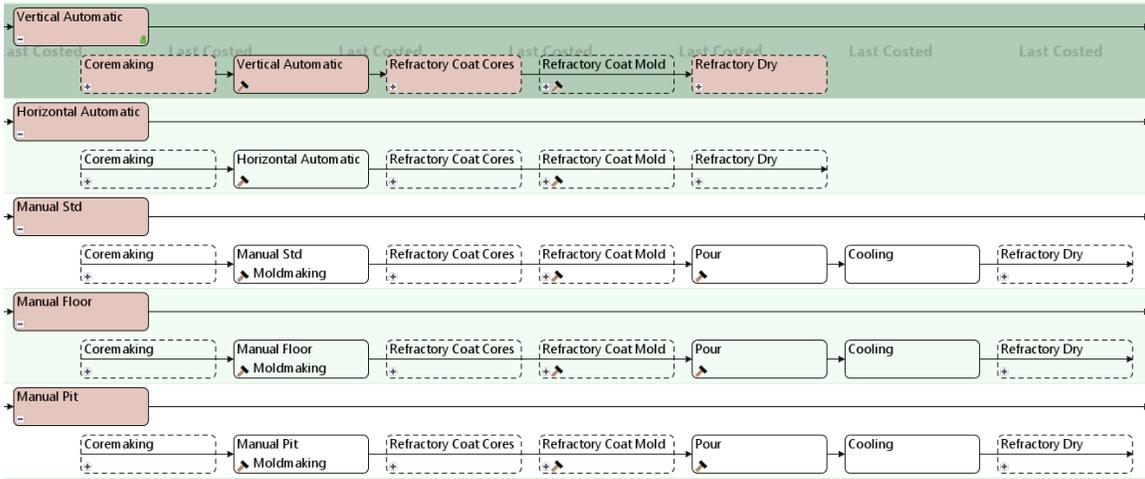
- Shakeout
- Degating (optional—see below)
- Cleaning
- Finishing
- Visual Inspection

Degating is included in the routing unless the part material is listed with **No** for **Can Degate** in the lookup table **tblCanDegate**.

Can Degate	Material Type
No	Ductile Iron
No	Gray Iron
No	Malleable Cast Iron
Yes	Aluminum
Yes	Aluminum Bronze
Yes	Brass
Yes	Bronze
Yes	Copper
Yes	Magnesium
Yes	Manganese Bronze
Yes	Silicon Brass
Yes	Stainless Steel
Yes	Steel
Yes	Zinc
Yes	Zinc-Aluminum

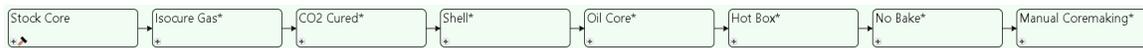
The Molding and Coring routing has a variety of alternative sub-routings, which are shown in the diagrams below.





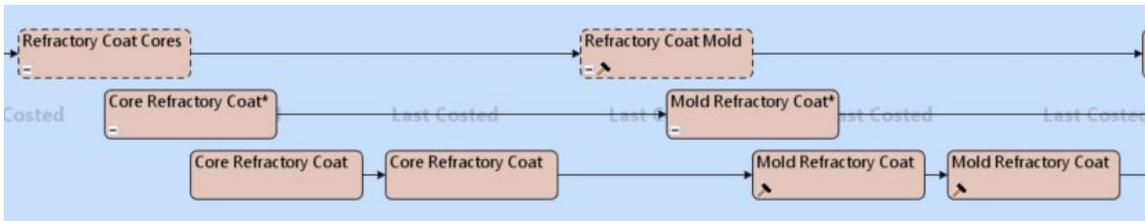
See [Sand Casting General Process](#) and [Sand Casting Process-level Feasibility](#) for more information on mold-making processes.

The core-making routings that are shown in the diagram above each have 0 or more occurrences of each of the processes shown below.

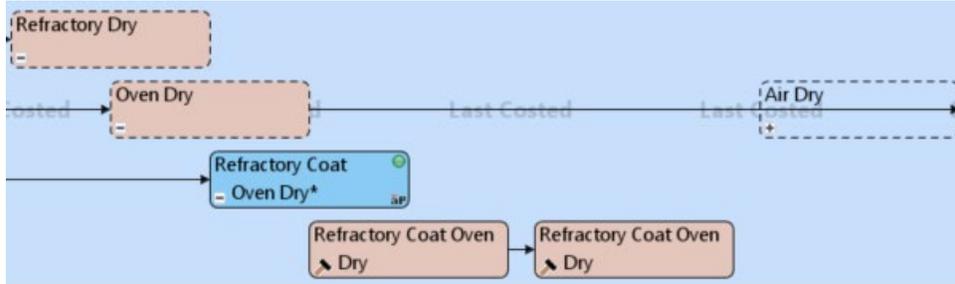


See [Coremaking Feasibility and Routing for Sand Casting](#) for more information.

By default in starting point VPEs, refractory coating and drying are assumed to be applied to any cores, as well as to any molds created by manual moldmaking. (Refractory coating is also known as "foundry coating", "protective coating", "wash", and "blacking".) There can be multiple instances of a mold or core coating process in order to model the application of multiple coats. See [Mold Refractory Coat](#) and [Core Refractory Coat for Sand Casting](#) for more information.



Cores and molds are oven dried by default, if they can fit in an oven; otherwise they are air dried. There can be multiple instances of a drying process in order to model drying after each of multiple coats. See [Refractory Coat Oven Dry for Sand Casting](#) and [Refractory Coat Air Dry for Sand Casting](#).



Users can also manually include refractory coating and drying of molds that are created by automatic molding. In addition, users can manually include air drying instead of oven drying. See [Refractory Coating Setup Options for Sand Casting](#) for more information.

If you have licensed the Machining process group, your routing can include any of the following secondary processes:

- 3-Axis Milling
- Cylindrical Grinding
- Gun Drill
- 2-axis Wire EDM operations
- Single Index Milling and Rotor Grinding operations (if helical groove geometry is present)

If you have licensed the optional Turning module, your routing can include the turning processes using the following lathe types:

- 2-axis
- 3-axis,
- 4-axis
- 6-axis

Note that if you select **This part is not machined** in the Production Scenario tab of the Cost Guide, but then manually select any GCD operation sequences which require machining, the corresponding GCDs will fail to cost with the message **User-selected operations are unavailable in the current routing**.

Your routing can also include processes from the following process groups, if you have licensed these modules:

- Heat Treatment
- Surface Treatment
- Other Secondary Processes, including packaging, Xray inspection, and various types of testing.

Sand Casting Process-level Feasibility

Sand Casting, by default, does not place a feasibility constraint on part thickness. But if the Sand Casting setup option **Minimum Wall Thickness Check** is set to **true** (it is **false** by default), then Sand Casting is feasible only if the part's **Minimum Thickness** equals or exceeds the material's **Minimum Wall Thickness**. Similarly, if the Sand Casting setup

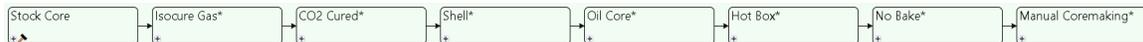
option **Maximum Wall Thickness Check** is set to **true** (it is **false** by default), then Sand Casting is feasible only if the part's **Maximum Thickness** equals or exceeds the material's **Maximum Wall Thickness**.

Degating is included in the routing unless the part material is listed with **No** for **Can Degate** in the lookup table **tblCanDegate**. In starting point VPEs, the following materials are listed as incompatible with Degating: Ductile Iron, Gray Iron, Malleable Cast Iron.

See [Coremaking Feasibility and Routing for Sand Casting](#) for information on feasibility requirements for coremaking processes for sand casting.

Coremaking Feasibility and Routing for Sand Casting

The core-making routings (see [Sand Casting Process-level Routing](#)) each have 0 or more occurrences of each of the coremaking processes shown below.



See [Sand Casting General Process](#) for a description of each coremaking method.

Which processes are included in a routing depends on which features are cored features. A GCD is considered to be a cored feature if it is obscured from the draw direction (and so not assigned a moldmaking operation—see [Sand Casting Operation-level Feasibility](#)).

The stock core process has at most one occurrence, which accounts for all the features that can be handled by a stock core (because, roughly, they have a standard diameter and length—see [Stock Core Feasibility](#)). Each other coremaking process generally has one occurrence for each segment of each core that is made by the process's associated coremaking method. (By default, each cored feature has a single-segment core, but see [Customizing the Number of Core Segments](#).) An exception to this occurs for some groups of simple hole cores or multistep hole cores that are similar in size; for such a group, a single occurrence may handle all the holes in the +group.

The following example shows the process-operation hierarchy for a part that has three voids handled by Isocure Gas coring, and two voids handled by No Bake coring:

Process Step	VPE	Machine
📁 Casting - Sand	aPriori Base VPE	
🔨 Melting	aPriori Base VPE	Cupola
📁 Molding and Coring	aPriori Base VPE	
📁 Coremaking [2]	aPriori Base VPE	
🔨 Isocure Gas [1]	aPriori Base VPE	DISACORE 10 MP
🔨 Isocure Gas Coring	aPriori Base VPE	
🔨 Isocure Gas		
🔍 Void:1	aPriori Base VPE	
🔨 Isocure Gas:2 [1]	aPriori Base VPE	DISACORE 10 MP
🔨 Isocure Gas Coring:2	aPriori Base VPE	
🔨 Isocure Gas		
🔍 Void:2	aPriori Base VPE	
🔨 Isocure Gas:3 [1]	aPriori Base VPE	DISACORE 40 MP
🔨 Isocure Gas Coring:3	aPriori Base VPE	
🔨 Isocure Gas		
🔍 Void:5	aPriori Base VPE	
🔨 No Bake [1]	aPriori Base VPE	Coremaker - 4,300mm x 3,800mm x 1,600m...
🔨 No Bake Coring	aPriori Base VPE	
🔨 No Bake		
🔍 Void:6	aPriori Base VPE	
🔨 No Bake:2 [1]	aPriori Base VPE	Beardsley & Piper ABC-250
🔨 No Bake Coring:2	aPriori Base VPE	
🔨 No Bake		
🔍 Void:7	aPriori Base VPE	
🔨 Manual Floor Moldmaking	aPriori Base VPE	Standard Flask(100X100X36in)
🔨 Pour	aPriori Base VPE	Ladle - 30,000kg Pour Capacity
🔨 Cooling	aPriori Base VPE	Default

Note that the coremaking processes each have a component-level child operation. The component-level operation itself has a child operation assigned to a particular hole or void GCD.

Each process occurrence often has only a single operation assigned to a cored feature, so that different cored features can use different machines even if they use the same coremaking method. For example, two cored features that differ significantly in size can use cores made by different isocure gas machines.

Manufacturing Process			
Edit View		Primary Process Group: casting-Sand	Material: Aluminum AL380 (aPriori USA)
Status	Process Step	VPE	Machine
●	117502900995401	aPriori USA	
●	▶ Casting - Sand	aPriori USA	
●	▶ Melting	aPriori USA	Cupola
●	▶ Molding and Coring	aPriori USA	
●	▶ Coremaking [5]	aPriori USA	
●	▶ Isocure Gas [1]	aPriori USA	DISACORE 10 MP
●	▶ Isocure Gas:2 [1]	aPriori USA	DISACORE 10 MP
●	▶ Isocure Gas:3 [1]	aPriori USA	DISACORE 40 MP
●	▶ Isocure Gas:4 [1]	aPriori USA	Coremaker - 4,300mm x 3,800mm x 1,600m...
●	▶ Isocure Gas:5 [1]	aPriori USA	Beardsley & Piper CB-30-CC
●	▶ Manual Floor Moldmaking	aPriori USA	Standard Flask(100X100X36in)
●	▶ Pour	aPriori USA	Ladle - 30,000kg Pour Capacity
●	▶ Cooling	aPriori USA	Default
●	▶ Shakeout	aPriori USA	Vertical Shakeout Table
●	▶ Degating	aPriori USA	Victor Technologies HC 1200C
●	▶ Cleaning	aPriori USA	Room Blast
●	▶ Finishing	aPriori USA	Hand Grind

See [Coremaking Machine Selection](#) for more information.

How aPriori Chooses a Coremaking Method

The coremaking method associated with a given feature is determined as follows:

- Stock Core handles holes that, roughly, have a standard length and diameter (see [Stock Core Feasibility](#)).
- Other cored features are handled by the most preferred method that has a feasible machine (see [Coremaking Machine Selection](#)) and can accommodate the mass of the required core. The following table lists the coremaking processes, in preference order, together with the maximum core weight that the process can accommodate:

Method (in preference order)	Max Core Weight in Starting Point VPEs	Max Core Weight Cost Model Variable
Isocure Gas (1st choice)	115kg	maxWeightGasCore
CO2 Cured	115kg	maxWeightGasCuredCore
Shell	5kg	maxWeightShellCore
Oil Core	115kg	maxWeightGasCuredCore
Hot Box	70kg	maxWeightHotBoxCore
No Bake	None	None
Manual (last choice)	None	None

Core weight is calculated based on sand density and core volume. Sand density is looked up by sand type in the lookup table **tblSand**; the sand type for each

coremaking process is specified by the toolshop variable **coreSandType**. Note also that core volume includes coreprint volume (see [Coremaking Machine Selection](#)).

Manual coremaking is chosen only if there is no feasible No Bake machine.

Coremaking Feasibility

A GCD is considered feasible for coremaking only if it has all the following characteristics:

- Voids:
 - At least one opening
 - Some exposed area (for core prints)
 - Nonzero tool reach
 - Sufficiently small aspect ratio. Aspect ratio is tool reach divided by virtual diameter, and is considered sufficiently small if it is less than the value of the site variable **maxCoreAspectRatio** (18 by default). Virtual diameter is the square root of the ratio of exposed area to number of openings.
- Holes:
 - Diameter that equals or exceeds the value of the cost model variable **minSandCastableHoleDiameter** (6.4mm in starting point VPEs).
 - Sufficiently small aspect ratio. Aspect ratio is length divided by diameter, and is considered sufficiently small if it is not greater than the value of the site variable **maxCoreAspectRatio** (18 by default).

Additional feasibility constraints are described in [Stock Core Feasibility](#) and [Feasibility for Coremaking Except Stock Core](#). See also [How aPriori Chooses a Coremaking Method](#).

Stock Core Feasibility

The Stock Core process is included in the routing if there are any Simple Hole GCDs with all the following characteristics:

- Hole is obscured (not oriented in the draw direction).
- Draft angle is 0, if the setup option Should Check Drafts is set to **true**.
- The lookup table **tblStockCores** lists a core with both the following characteristics:
 - Hole diameter equals the core diameter or exceeds it by no more than the value of the cost model variable **coreDiameterPlay** (1.5875mm in starting point VPEs).
 - Core length exceeds the length of the hole by at least the value of the cost model variable **lengthCorePrint** (10mm in starting point VPEs).

Description	Diameter (mm)	Length (mm)	Sticks Per Hour	Supplier
Stick, 1 1/16 in. dia x 24 in. long	26.99	609.60	50.29	Made In-House
Stick, 1 1/2 in. dia x 24 in. long	38.10	609.60	44.12	Made In-House
Stick, 1 1/4 in. dia x 24 in. long	31.75	609.60	47.65	Made In-House
Stick, 1 1/8 in. dia x 24 in. long	28.57	609.60	49.41	Made In-House
Stick, 1 11/16 in. dia x 24 in. long	42.86	609.60	41.47	Made In-House
Stick, 1 13/16 in. dia x 24 in. long	46.04	609.60	39.71	Made In-House
Stick, 1 15/16 in. dia x 24 in. long	49.21	609.60	37.94	Made In-House
Stick, 1 3/16 in. dia x 24 in. long	30.16	609.60	48.53	Made In-House
Stick, 1 3/4 in. dia x 24 in. long	44.45	609.60	40.59	Made In-House
Stick, 1 3/8 in. dia x 24 in. long	34.92	609.60	45.88	Made In-House
Stick, 1 5/16 in. dia x 24 in. long	33.34	609.60	46.76	Made In-House
Stick, 1 5/8 in. dia x 24 in. long	41.27	609.60	42.35	Made In-House
Stick, 1 7/16 in. dia x 24 in. long	36.51	609.60	45.00	Made In-House

Feasibility for Coremaking Except Stock Core

Generally, a coremaking operation is feasible for a given GCD only if all the following hold:

- Aspect ratio is acceptable. The aspect ratio is, roughly speaking, the GCD's diameter to length ratio:
 - For Simple Holes, the geometric properties **Diameter** and **Length** are used.
 - For Multistep Holes, the geometric properties **Min Diameter** and **Total Length** are used.
 - For Voids and ComboVoids, diameter is considered to be the square root of the ratio of the GCD's **Exposed Area** to its **Number of Openings**, and the length is the geometric property **Tool Reach**.

The threshold for acceptable aspect ratios is specified by the site variable **maxCoreAspectRatio** (18 in starting point VPEs).

- Roughness and tolerance (if specified) are achievable by the current routing. In starting point VPEs, roughness must be no better than 12.5 microns, and tolerance no tighter than IT 14, for routings without machining.
- Length is not too long for the selected machine, that is, the machine property **Max Corebox Length** is greater than or equal to the longest dimension of the corebox required for the GCD. See [Coremaking Machine Selection](#).
- Length is not too short for the selected machine, that is, the machine property **Smallest Core** is less than or equal to the following:
 - For Simple Holes, the geometric property **Length**
 - For Multistep Holes, the geometric property **Total Length**
 - For Voids and Combo Voids, the geometric property **Box Length**
- Size is not too small to be castable; that is, the cost model variable **minSandCastableHoleDiameter** (6.4mm in starting point VPEs) is less than or equal to the following:
 - For Simple Holes, **Diameter**

- For Multistep Holes, **Min Diameter**
- For Voids and ComboVoids, both **Box Height** and **Box Width**

See [Sand Casting Operation-level Feasibility](#) for operation feasibility by GCD type.

Note: Sand casting coremaking processes allow you to customize the number of coring operations for a given feature. By default, each cored feature is assumed to have a single-segment core, and so has one associated coring operation. For coremaking processes, you can override the default by editing the operation sequence for a cored feature—see [Customizing the Number of Core Segments](#) for more information.

Sand Casting Operation-level Feasibility

Below are the Sand Casting (SC) operations that have associated feasibility rules, grouped by GCD type. Each operation is accompanied by necessary conditions for the operation's feasibility. See also [Coremaking Feasibility and Routing for Sand Casting](#).

Curved Surface

- *GreenSandCSurfaceSandCasting*
 - Surface area is nonzero.
 - Tolerance is nonzero.
 - Roughness is nonzero.
 - Tolerance is not too small to cast.
 - Surface roughness is not too small to cast.

Curved Wall

- *GreenSandCWallSandCasting*
 - Surface area is nonzero.
 - Tolerance is nonzero.
 - Roughness is nonzero.
 - Tolerance is not too small to cast.
 - Surface roughness is not too small to cast.
 - Surface draft angle is not too small to cast (according to the plant variable **minCastableDraft**, if drafts checking is enabled (see [User Inputs](#))).
 - Surface edge is not too sharp to cast, if rounds checking is enabled (see [User Inputs](#)).
- *SandCasting*
 - GCD is not threaded.

Void and ComboVoid

- *IsocureGasVoidCoring*
 - Exposed area is nonzero.
 - Core size is not too large or too small (according to machine properties **smallestCore** and **maxCoreboxLength**, as well as plant variables **lengthCorePrint** and **coreboxLengthAllowance**).
 - Number of openings is nonzero.

- *CO2CuredVoidCoring*
 - Exposed area is nonzero.
 - Core size is not too large or too small (according to machine properties **smallestCore** and **maxCoreboxLength**, as well as plant variables **lengthCorePrint** and **coreboxLengthAllowance**).
 - Number of openings is nonzero.
- *OilCoreVoidCoring*
 - Exposed area is nonzero.
 - Core size is not too large or too small (according to machine properties **smallestCore** and **maxCoreboxLength**, as well as plant variables **lengthCorePrint** and **coreboxLengthAllowance**).
 - Number of openings is nonzero.
- *HotBoxVoidCoring*
 - Exposed area is nonzero.
 - Core size is not too large or too small (according to machine properties **smallestCore** and **maxCoreboxLength**, as well as plant variables **lengthCorePrint** and **coreboxLengthAllowance**).
 - Number of openings is nonzero.
- *NoBakeVoidCoring*
 - Exposed area is nonzero.
 - Core size is not too large or too small (according to machine properties **smallestCore** and **maxCoreboxLength**, as well as plant variables **lengthCorePrint** and **coreboxLengthAllowance**).
 - Number of openings is nonzero.
- *ShellVoidCoring*
 - Core size is not too large or too small (according to machine properties **smallestCore** and **maxCoreboxLength**, as well as plant variables **lengthCorePrint** and **coreboxLengthAllowance**).
- *Coring*
 - Virtual diameter is nonzero.
 - Exposed area is nonzero.
 - Tool reach is nonzero.
 - Number of openings is nonzero.
 - Aspect ratio is not too large (that is, tool reach over virtual diameter is less than or equal to the plant variable **maxCoreAspectRatio**).
- *SandCasting*
 - Box width is not too small to cast (that is, diameter is greater than the plant variable **minSandCastableHoleDia**).
 - Box height is not too small to cast (that is, diameter is greater than the plant variable **minSandCastableHoleDia**).
- *GreenSandVoidCasting*
 - Virtual diameter is nonzero.

- GCD is not obscured.
- GCD is not undercut.
- Exposed area is nonzero.
- Tool reach is nonzero.
- Number of openings is nonzero.
- Aspect ratio (tool reach divided by virtual diameter) is not too large (according to the plant variables **greenSandSmallHoleDia**, **greenSandSmallVoidAspect**, and **greenSandLargeVoidAspect**).

Multistep Hole

- *Coring*
 - Aspect ratio is not too large (that is, length over minimum diameter is greater than the plant variable **maxCoreAspectRatio**).
- *GreenSandMStepCasting*
 - Diameter is nonzero.
 - Diameter is not too small to cast (according to the plant variable **minSandCastableHoleDia**).
 - Accessibility is not obscure (that is, GCD is accessible from the draw direction).
 - Aspect ratio is not too large (according to the plant variables **greenSandSmallHoleDia**, **greenSandSmallHoleAspect**, and **greenSandLargeHoleAspect**).
- *SandCasting*
 - Minimum diameter is not too small to cast (according to the plant variable **minSandCastableHoleDia**).
 - Minimum wall thickness is not too small (according to the material property **minWallThickness**).
- *SandCastingOnly*
 - Diametrical tolerance is nonzero.
 - Roughness is nonzero.
 - Diametrical tolerance is not too small to cast.
 - Surface roughness is not too small to cast.
 - Surface edge is not too sharp to cast, if rounds checking is enabled (see [User Inputs](#)).
- *IsocureGasMStepCoring*
 - Minimum diameter is nonzero.
 - Core size is not too large or too small (according to machine properties **smallestCore** and **maxCoreboxLength**, as well as plant variables **lengthCorePrint** and **coreboxLengthAllowance**).
 - Roughness is not too small to cast (according to the machine property **roughnessCapability**).
- *CO2CuredMStepCoring*
 - Minimum diameter is nonzero.

- Core size is not too large or too small (according to machine properties **smallestCore** and **maxCoreboxLength**, as well as plant variables **lengthCorePrint** and **coreboxLengthAllowance**).
- Roughness is not too small to cast.
- *OilCoreMStepCoring*
 - Minimum diameter is nonzero.
 - Core size is not too large or too small (according to machine properties **smallestCore** and **maxCoreboxLength**, as well as plant variables **lengthCorePrint** and **coreboxLengthAllowance**).
 - Roughness is not too small to cast.
- *HotBoxMStepCoring*
 - Minimum diameter is nonzero.
 - Core size is not too large or too small (according to machine properties **smallestCore** and **maxCoreboxLength**, as well as plant variables **lengthCorePrint** and **coreboxLengthAllowance**).
 - Roughness is not too small to cast).
- *NoBakeMStepCoring*
 - Minimum diameter is nonzero.
 - Core size is not too large or too small (according to machine properties **smallestCore** and **maxCoreboxLength**, as well as plant variables **lengthCorePrint** and **coreboxLengthAllowance**).
 - Roughness is not too small to cast.
- *ShellMStepCoring*
 - Core size is not too large or too small (according to machine properties **smallestCore** and **maxCoreboxLength**, as well as plant variables **lengthCorePrint** and **coreboxLengthAllowance**).
 - Roughness is not too small to cast.

Planar Face

- *GreenSandPFaceSandCasting*
 - Surface area is nonzero.
 - Tolerance is nonzero.
 - Roughness is nonzero.
 - Tolerance is not too small to cast.
 - Surface roughness is not too small to cast.
 - Surface draft angle is not too small to cast (according to the plant variable **minCastableDraft**), if drafts checking is enabled (see [User Inputs](#)).
 - Surface edge is not too sharp to cast, if rounds checking is enabled (see [User Inputs](#)).

Ring

- *SandCastAsComboVoid*
 - GCD is not ID-only approachable.

- Ring length is not too short (according to the plant variable **minCastableRingLength**).
- *SandCastAsRingedHole*
 - Ring length is not too short (according to the machine property **smallestCore**).
- *GreenSandRingCasting*
 - GCD is not ID-only approachable.
 - Ring length is not too short (according to the plant variable **minCastableRingLength**).

Ringed Hole

- *GreenSandRingedHoldCasting*
 - Diameter is nonzero.
 - Diameter is not too small to cast (according to the plant variable **minSandCastableHoleDia**).
 - Aspect ratio is not too large (that is, length over minimum diameter is greater than the plant variable **maxCoreAspectRatio**).
- *CO2 Cured Coring*
 - Minimum diameter is nonzero.
 - Core size is not too large (according to machine properties **maxCoreboxHeight** and **maxCoreboxLength**, as well as plant variables **lengthCorePrint** and **coreboxLengthAllowance**).
- *Hot Box Coring*
 - Minimum diameter is nonzero.
 - Core size is not too large (according to machine properties **maxCoreboxHeight** and **maxCoreboxLength**, as well as plant variables **lengthCorePrint** and **coreboxLengthAllowance**).
- *Isocure Gas Coring*
 - Minimum diameter is nonzero.
 - Core size is not too large (according to machine properties **maxCoreboxHeight** and **maxCoreboxLength**, as well as plant variables **lengthCorePrint** and **coreboxLengthAllowance**).
- *No Bake Coring*
 - Minimum diameter is nonzero.
 - Core size is not too large (according to machine properties **maxCoreboxHeight** and **maxCoreboxLength**, as well as plant variables **lengthCorePrint** and **coreboxLengthAllowance**).
- *Oil Core Coring*
 - Minimum diameter is nonzero.
 - Core size is not too large (according to machine properties **maxCoreboxHeight** and **maxCoreboxLength**, as well as plant variables **lengthCorePrint** and **coreboxLengthAllowance**).
- *Shell Coring (SC Coring)*
 - Minimum diameter is nonzero.

- Core size is not too large (according to machine properties **maxCoreboxHeight** and **maxCoreboxLength**, as well as plant variables **lengthCorePrint** and **coreboxLengthAllowance**).

Simple Hole

- *Coring*
 - Diameter is nonzero.
 - Diameter is not too small to cast (according to the plant variable **minSandCastableHoleDia**).
 - Aspect ratio is not too large (that is, length over minimum diameter is greater than the plant variable **maxCoreAspectRatio**).
- *GreenSandHoleCasting*
 - Diameter is nonzero.
 - Diameter is not too small to cast (according to the plant variable **minSandCastableHoleDia**).
 - GCD is not obscured.
 - Surface draft angle is not too small to cast (according to the plant variable **minCastableDraft**), if drafts checking is enabled (see [User Inputs](#)).
 - Aspect ratio is not too large (according to the plant variables **greenSandSmallHoleDia**, **greenSandSmallHoleAspect**, and **greenSandLargeHoleAspect**).
- *SandCasting*
 - Diameter is not too small to cast (according to the plant variable **minSandCastableHoleDia**).
 - Minimum wall thickness is not too small (according to the material property **minWallThickness**).
- *IsocureGasHoleCoring*
 - Diameter is nonzero.
 - Core size is not too large or too small (according to machine properties **smallestCore** and **maxCoreboxLength**, as well as plant variables **lengthCorePrint** and **coreboxLengthAllowance**).
 - Roughness is not too small to cast.
- *CO2CuredHoleCoring*
 - Diameter is nonzero.
 - Core size is not too large or too small (according to machine properties **smallestCore** and **maxCoreboxLength**, as well as plant variables **lengthCorePrint** and **coreboxLengthAllowance**).
 - Roughness is not too small to cast.
- *OilCoreHoleCoring*
 - Diameter is nonzero.
 - Core size is not too large or too small (according to machine properties **smallestCore** and **maxCoreboxLength**, as well as plant variables **lengthCorePrint** and **coreboxLengthAllowance**).

- Roughness is not too small to cast.
- *HotBoxHoleCoring*
 - Diameter is nonzero.
 - Core size is not too large or too small (according to machine properties **smallestCore** and **maxCoreboxLength**, as well as plant variables **lengthCorePrint** and **coreboxLengthAllowance**).
 - Roughness is not too small to cast.
- *NoBakeHoleCoring*
 - Diameter is nonzero.
 - Core size is not too large or too small (according to machine properties **smallestCore** and **maxCoreboxLength**, as well as plant variables **lengthCorePrint** and **coreboxLengthAllowance**).
 - Roughness is not too small to cast.
- *ShellHoleCoring*
 - Core size is not too large or too small (according to machine properties **smallestCore** and **maxCoreboxLength**, as well as plant variables **lengthCorePrint** and **coreboxLengthAllowance**).
 - Roughness is not too small to cast.
- *StockCoreHoleCoring*
 - Diameter is nonzero.
 - The GCD has a zero-draft wall (that is, the GCD is extruded).
 - Diameter and length must match a stock extruder die (according to the **stockCores** lookup table and plant variables **coreDiameterPlay** and **lengthCorePrint**).
 - GCD is obscured (GCD is perpendicular to the draw direction).
 - Draft angle is not too small to cast (according to the plant variable **minCastableDraft**), if drafts checking is enabled (see [User Inputs](#)).
- *SandCastingOnly*
 - GCD has no threads.
 - Diametrical tolerance is nonzero.
 - Roughness is nonzero.
 - Diametrical tolerance is not too small to cast (according the lookup table **toleranceCapabilitySandCasting**).
 - Surface roughness is not too small to cast.
 - Surface edge is not too sharp to cast, if rounds checking is enabled (see [User Inputs](#)).

Material Selection for Sand Casting

In direct integration mode with Pro/ENGINEER, if the composition selection mode is **MCAD**, aPriori selects the MCAD composition from the part, if available. Otherwise aPriori selects the VPE default material (Aluminum AL380 for all baseline VPEs).

In CAD-independent mode, aPriori selects the VPE default material (Aluminum AL380 for all baseline VPEs).

In both direct integration and CAD-independent mode, you can either use aPriori's selection or else manually select a material composition and override the material unit cost. To manually specify a material, select **Edit > Material Selection** in the Manufacturing Process pane (see also [Selecting material in Manufacturing Process Information](#)).

Machine Feasibility and Selection for Sand Casting

This section contains the following subsections:

- [Molding Machine Selection](#)
- [Shakeout Machine Selection](#)
- [Degating Machine Selection](#)
- [Cleaning Machine Selection](#)
- [Coremaking Machine Selection](#)
- [Refractory Coat Oven Dry Machine Selection](#)

Molding Machine Selection

If aPriori is configured to automatically select a molding machine, it selects the machine with the lowest flask volume that satisfies all the machine feasibility rules.

aPriori selects only from preferred machines, if there is a feasible preferred machine and the cost model variable **usePreferredMachines** is set to **true** (the default in starting point VPEs). If there is no feasible preferred machine, or if the cost model variable **usePreferredMachines** is set to **false**, aPriori selects from all machines. A machine is preferred if the machine property **isPreferred** (typically displayed as **Is Preferred**) is **true**.

The feasibility rules require that the mold required for the part can fit on the machine. More specifically, a machine is feasible only if both the following are true:

- Mold length and width fit the machine flask.
- Part height along with the required sand depth is less than or equal to the height of the machine flask. depends on the machine's

aPriori calculates the mold dimensions and clamp force required for a given part based on a number of factors, including the minimum required number of cavities in the mold. If you don't use the PSO **Number of Cavities** (see [User Inputs](#)), the minimum required number of cavities is 1, so aPriori finds a machine that can accommodate at least a single-cavity mold.

By using the PSO, you can specify the number of cavities explicitly or specify that aPriori should use the combination of machine and number of cavities that results in the lowest per part cost. Calculation of clamp force is described in [Required Clamp Force](#). Calculation of the number of cavities assumed for cost estimates is described in [Number of Mold Cavities](#).

To manually select a machine for a given process, select **Edit > Routing Selection** in the Manufacturing Process pane, right-click on the process in the Routing Selection window, and select **Machine Selection** from the context menu (see also Selecting a machine for an operation in Manufacturing Process Information).

Shakeout Machine Selection

aPriori selects the *feasible* machine (see below) with the smallest weight capacity per part:

$$\text{Weight Capacity per Part} = \frac{\text{Machine Weight Capacity}}{\text{Number of Parts That Can Fit On Machine}}$$

The number of parts that can fit on the machine depends on the machine's **Shakeout Type**:

- **conveyor**: the number of parts is always 1.
- **manual**: the number of parts is always 1.
- **table**: the number of parts is the maximum number parts that satisfy both the *space constraint* and the *weight constraint* (see below).

aPriori selects only from preferred machines, if there is a feasible preferred machine and the cost model variable **usePreferredMachines** is set to **true** (the default in starting point VPEs). If there is no feasible preferred machine, or if the cost model variable **usePreferredMachines** is set to **false**, aPriori selects from all machines. A machine is preferred if the machine property **isPreferred** (typically displayed as **Is Preferred**) is **true**.

Space constraint: The maximum number of parts that can satisfy the space constraint is determined as follows:

- 1 Find the maximum number of lengthwise-oriented parts that fit on the machine table.

$$\text{rounddown} \left(\frac{\text{Machine Length}}{\text{Part Length} + \text{Part Spacing}} \right) * \text{rounddown} \left(\frac{\text{Machine Width}}{\text{Part Width} + \text{Part Spacing}} \right)$$

(Lengthwise orientation means that the part's length is aligned with the table's length and the part's width is aligned with the table's width.)

Part Spacing is specified by the cost model variable **shakeoutTablePartDistance** (50mm in starting point VPEs).

- 2 Find the maximum number of widthwise-oriented parts that fit.

$$\text{rounddown} \left(\frac{\text{Machine Length}}{\text{Part Width} + \text{Part Spacing}} \right) * \text{rounddown} \left(\frac{\text{Machine Width}}{\text{Part Length} + \text{Part Spacing}} \right)$$

(Widthwise orientation means that the part's width dimension is aligned with the table's length and the part's length is aligned with the table's width.)

Part Spacing is specified by the cost model variable **shakeoutTablePartDistance** (50mm in starting point VPEs).

-
-
- 3 Pick the larger of the values found in 1 and 2, above. This is the maximum number of parts that satisfy the space constraint (unless it is 0, in which the Number of Parts is 1).

Weight constraint: The maximum number of parts that can satisfy the weight constraint is the result of rounding down the quotient of the machine's weight capacity and the part weight:

rounddown(Machine Weight Capacity / Part Weight)

Machine weight capacity is specified by the machine property **Weight Capacity**. Part weight is the product of the part's **Volume** and the material's **Density**.

Feasible machine: A machine is feasible if both the following hold:

- At least one part satisfies the machine's weight constraint (see above).
- At least one of the following holds:
 - Part length is less than the cost model variable **maxAutoShakeoutLength** (3000mm in starting point VPEs).
 - Machine **Shakeout Type** is **manual**.

Degating Machine Selection

aPriori selects the smallest feasible machine (by weight capacity) that can accommodate the part's weight. Weight capacity is specified by the machine property **Max Weight**.

aPriori selects only from preferred machines, if there is a feasible preferred machine and the cost model variable **usePreferredMachines** is set to **true** (the default in starting point VPEs). If there is no feasible preferred machine, or if the cost model variable **usePreferredMachines** is set to **false**, aPriori selects from all machines. A machine is preferred if the machine property **isPreferred** (typically displayed as **Is Preferred**) is **true**.

A machine is feasible only if its weight capacity exceeds the part weight. In addition, a machine that uses **OxyFuel** is *not* feasible for aluminum parts.

Cleaning Machine Selection

There are four types of cleaning machines, all of which use shot blast:

- **Tumble Blast:** Uses wheel blasting. Parts are placed in a rotating barrel, causing them to tumble, exposing all surfaces to the shot stream.
- **Table Blast:** Uses wheel blasting. One or more parts are placed on a table that rotates, exposing them to the shot stream. The cost model assumes that parts are turned over or re-positioned by hand during a pause in blasting.
- **Chamber Blast:** For large parts. Uses shot blasting in an automated chamber that can accommodate multiple, large parts. The cost model assumes that the part is reoriented during a pause in blasting.
- **Room Blast:** For very large parts. Uses air blasting. In a cleaning room, an operator manually directs shot at a single part, or a robot programmatically directs shot at the part. The cost model assumes that the part is reoriented during a pause in blasting.

The machine type is specified by the machine property **Type**.

aPriori selects the smallest machine (by weight capacity) that is feasible for the current part (see below). aPriori selects only from preferred machines, if there is a feasible preferred machine and the cost model variable **usePreferredMachines** is set to **true** (the default in starting point VPEs). If there is no feasible preferred machine, or if the cost model variable **usePreferredMachines** is set to **false**, aPriori selects from all machines. A machine is preferred if the machine property **isPreferred** (typically displayed as **Is Preferred**) is **true**.

A machine is feasible if it can accommodate all the following:

- Weight of a load with at least the minimum number of parts required for an economic load.
- Height of the part.
- Length or width of the part, whichever is smaller
- Volume (for Tumble Blast) or area (for Table Blast) of a load with at least the minimum number of parts required for an economic load.

The minimum number of parts in an economic load is specified by the machine property **Min Number Parts**.

Finishing Machine Selection

aPriori selects the smallest machine (by weight capacity) that can accommodate the part's weight. Weight capacity is specified by the machine property **Max Weight**.

aPriori selects only from preferred machines, if there is a feasible preferred machine and the cost model variable **usePreferredMachines** is set to **true** (the default in starting point VPEs). If there is no feasible preferred machine, or if the cost model variable **usePreferredMachines** is set to **false**, aPriori selects from all machines. A machine is preferred if the machine property **isPreferred** (typically displayed as **Is Preferred**) is **true**.

Coremaking Machine Selection

For each occurrence of each coremaking process (except Stock Core), aPriori selects the machine with the smallest corebox capacity that is feasible (see below). aPriori selects only from preferred machines, if there is a feasible preferred machine and the cost model variable **usePreferredMachines** is set to **true** (the default in starting point VPEs). If there is no feasible preferred machine, or if the cost model variable **usePreferredMachines** is set to **false**, aPriori selects from all machines. A machine is preferred if the machine property **isPreferred** (typically displayed as **Is Preferred**) is **true**.

A coremaking machine is feasible if it can accommodate a corebox with at least one cavity for one segment of the core for the GCD associated with the process occurrence. Note that each occurrence of each coremaking process has exactly one associated GCD. Note also that by default, each core has a single segment, but you can override the default on a GCD-by-GCD basis—see [Customizing the Number of Core Segments](#).

For processes other than Manual Coremaking, a machine's corebox capacity is given by the machine properties **Max Corebox Length**, **Max Corebox Width**, and **Max Corebox Height**. A machine can accommodate a GCD if these dimensions equal or exceed the dimensions

of the corebox required for the GCD. For a single-segment core, the dimensions of the required corebox are the dimensions of the GCD's smallest enclosing box, extended to account for coreprints (extensions of sand for hanging the core in the mold), and supplemented by the corebox wall thickness (specified by the cost model variable **coreboxLengthAllowance**--19mm in starting point VPEs). For a multi-segment core, the dimensions of the required corebox are the dimensions of the GCD's smallest enclosing box divided by the number of segments, extended to account for coreprints, and supplemented by the corebox wall thickness.

The GCD properties **Dir CorePrints Box Length**, **Dir Core Prints Box Width**, and **Dir Core Prints Box Height** indicate which dimensions should be extended, and whether the dimension should be extended in one or both directions. For example, if **Dir Core Prints Box Length** is 0, this indicates that an extension along the length dimension is *not* required (because both directions are blocked by the part); if **Dir Core Prints Box Length** is 1, this indicates that the length should be extended in one direction to account for coreprints (because the other direction is blocked by the part); if **Dir Core Prints Box Length** is 2, this indicates that the length should be extended in both directions to account for coreprints (because neither direction is blocked).

The cost model variable **lengthCorePrint** (10mm in starting point VPEs) indicates the extension length in each direction. So, for example, if **Dir Core Prints Box Length** is 2, the GCD's box length dimension is extended by 10mm in each direction (20mm total), in starting point VPEs.

For Manual Coremaking, the machine represents a muller and vibratory core table. Machines are constrained by the total mass of all the part's cores, rather than by individual core dimensions. A machine's corebox capacity is given by the mass-valued machine property **Max Capacity**.

Refractory Coat Oven Dry Machine Selection

Machine selection for Refractory Coat Oven Dry picks the lowest-volume feasible machine. A machine is feasible if both the following hold:

- It can accommodate each of the part's oven-dryable cores
- It can accommodate the part's mold, if the mold is oven-dryable.

A core or mold is oven-dryable if it can fit in the *largest* available oven. Molds and cores that are too large for any available oven are air dried.

Note that the cost model assumes the use of a single oven for a given part, that is, the cost model assumes that the same oven is used for a part's mold (if it is oven-dried) as well as for all the part's oven-dried cores.

Machine volume is the product of the machine properties **Bed Length**, **Bed Width**, and **Bed Height**.

In starting point VPEs, which assume a spacing factor of 0.8, an oven can accommodate a core or mold (or, equivalently, a core or mold can fit in an oven) if all the following hold:

- Longest dimension of the bounding box of the mold or core is no greater than 80% if the machine **Bed Length**.

- Shortest dimension of the bounding box of the mold or core is no greater than 80% if the machine **Bed Height**.
- Intermediate dimension of the bounding box of the mold or core is no greater than 80% if the machine **Bed Width**.

Administrators can configure the spacing factor with the cost model variable **defaultRefractoryCoatOvenSpaceAvailableFactor** (0.8 in starting point VPEs).

See also [Mold and Core Bounding Box Dimensions](#).

Cost Algorithms and Calculations for Sand Casting

If machining processes are included as secondary processes on Casting components, then the machining costs are computed via the Machining cost model and combined with the casting process costs to produce a total manufacturing process cost.

Total casting costs aggregate the costs of material, labor, equipment, and tooling. Typically, tooling accounts for a significant portion of the total cost. The part's wall thickness and material (because they affect cooling time) have a significant impact on both labor and tooling costs.

This section details how costs are calculated by aPriori. Note that you can override the calculation of many of the quantities involved, and specify them explicitly—see [User Inputs](#), below.

When not otherwise specified, costs are per part.

This section covers formulas in the following areas:

- Yields for Sand Casting
- Material Cost and Utilization for Sand Casting
- Labor and Setup Costs for Sand Casting
- Melting Formulas for Sand Casting
- Degating Formulas
- Cleaning Formulas
- Finishing Formulas
- Visual Inspection Formulas
- Cope Height
- Design Complexity Factor
- Gating System Model
- Mold Making Formulas
- Coremaking—All Except Stock Core
- Coremaking--Stock Core
- Mold Refractory Coat
- Core Refractory Coat for Sand Casting
- Refractory Coat Oven Dry for Sand Casting
- Refractory Coat Air Dry for Sand Casting
- Pour Formulas
- Cool Formulas
- Shakeout Formulas
- Number of Mold Cavities
- Tooling Cost

Yields for Sand Casting

This section describes how yields are calculated for all Casting processes, except for coremaking processes.

Final Yield = Final Output Volume / Input Volume

Final yield affects labor and overhead costs per part (it does not affect material cost—but see Non-foundry Yield in [Material Cost and Utilization](#) for Sand Casting). It is the fraction of the total number of parts created by this process in the current production scenario that will survive as good parts once any secondary processes are completed. That is, final yield is the fraction of parts created by this process that are *not* discarded as scrap parts, either by this process or by a downstream process. Final yield depends on the following:

- Final output volume (product of the annual volume and number of production years, specified in the Production Scenario screen of the Cost Guide)
- Input volume (see the formula below). This is the total number of parts produced by this process, including all parts discarded as scrap from this process or downstream processes.

Input Volume = Local Output Volume + Number of Scrap Parts for This Process

Input volume is the total number of parts produced by this process in the current scenario, including all parts discarded as scrap from this process or downstream processes. It is the sum of the following:

- Local output volume (see the formula below). This is the number of parts produced by this process, excluding parts discarded as scrap by this process, but including parts that are discarded as scrap by downstream processes.
- Number of scrap parts for this process (see the formula below)

Local Output Volume = Final Output Volume + Number of Scrap Parts Downstream

Local output volume is the number of parts produced by this process in the current scenario, excluding parts discarded as scrap by this process, but including parts that are discarded as scrap by downstream processes. It is the sum of the following:

- Final output volume (product of volume and number of production years, specified in the Production Scenario screen of the Cost Guide)
- Number of Scrap Parts Downstream. This is the number of parts discarded as scrap by downstream processes.

Number of Scrap Parts for This Process = (Local Output Volume / Good Part Yield) – Local Output Volume

Number of scrap parts for this process is the number of parts produced by this process in the current scenario that are discarded as scrap by this process, before any downstream process is performed on them. It is a function of the following:

- Local output volume (see the formula above)
- Good part yield (specified by the machine property **Good Part Yield**). This is the fraction of parts produced by this process that are not discarded as scrap by this process but may be discarded as scrap by downstream processes.

Material Cost and Utilization for Sand Casting

This section describes how material cost and utilization are calculated for the Casting utilization process, Melting.

Material Cost = Rough Mass * Material Unit Cost

Material cost is the product of the following:

- Rough Mass (see formula)
- Material unit cost (specified by the material property **Cost**)

Rough Mass = Finish Mass / Utilization

Rough mass is the mass per part that accounts for material cost per part. In the default utilization mode, it is the sum of the following:

- Mass of the finished part
- Mass of the metal chips removed from the part by secondary machining operations
- Mass of the un-remeltable material lost per part due to spillage and oxidation
- Mass of the material lost due to parts scrapped by non-foundry processes (amortized over all parts in the current production scenario)

This assumes the following can be remelted, and so does not contribute to material cost:

- Parts scrapped by processes performed at the foundry
- Contents of the feeder system (runners, risers, etc.)

In all utilization modes, rough mass depends on the following:

- Finish mass (product of part volume and material density)
- Utilization (specified by the formula below, or specified in the Material Utilization section of the Material Selection dialog)

Utilization = Part Volume /

$$\frac{\text{Part Volume} + \text{Metal Chip Volume} + \text{Volume Loss} + \text{Non-remeltable Volume}}{\text{Non-foundry Yield}}$$

In the default utilization mode, utilization depends on the following:

- Part volume (determined by geometry extraction)
- Metal chip volume: derived by summing metal chip volume for each machining operation that is applied to the part. For fully-machined features, this calculation is based on feature volume. For machine-finished features, the calculation is based on the area of the finished surface. The calculation assumes that the depth of material removed during finishing is the value specified by the cost model variable **finishAllowance**.
- Volume loss (see formula)
- Non-remelable volume (see formula)
- Non-foundry yield (see formula)

Volume Loss = Mass Loss / Material Density

Volume loss is the pouring volume of metal that is oxidized or spilled during melting and cannot be re-melted. It is a function of the following:

- Mass loss. Specified by the formula below or the process setup option Mass Loss—see [Melting Setup Options](#).
- Material density (specified by a material property)

Mass Loss = Mass Poured Excluding Loss * (1 / (Machine Yield Loss * Material Yield Loss Factor) – 1)

Mass loss is the pouring mass of metal that is oxidized or spilled during melting and cannot be remelted. By default, it is specified by this formula. Users can override the default with the process setup option Mass Loss—see [Melting Setup Options](#). Computed mass loss is a function of the following:

- Mass poured excluding loss. See formula below.
- Machine yield loss: fraction of material not lost through spillage (specified by a machine property)
- Material yield loss factor: fraction of material not lost through oxidation (specified as a material property)

Mass Poured Excluding Loss = Mass Before Machining + Mass Waste

This is the portion of the mass poured per part that includes remeltable material from runners and risers, as well as material from scrapped parts (amortized over all the parts in the current production scenario), but does not include mass lost due to spillage and oxidation. It is the sum of the following:

- Mass before machining (see formula)
- Mass waste. Specified by the user with the process setup option Mass Waste (see [Melting Setup Options](#)) or calculated with the formula below.

Mass Before Machining = (Part Volume + Metal Chip Volume of Machined Features) * Material Density

Mass before machining is the part mass plus the mass removed by machining. It depends on the following:

- Part volume (obtained from GCD extraction)
- Metal chip volume of machined features: derived by summing metal chip volume for each machining operation that is applied to the part. For fully-machined features, this calculation is based on feature volume. For machine-finished features, the calculation is based on the area of the finished surface. The calculation assumes that the depth of material removed during finishing is the value specified by the cost model variable **finishAllowance**.
- Material density (specified by a material property)

Mass Waste = Total Gating Mass / Number of Cavities

Mass waste is the mass per cavity of that portion of the pouring volume contained in the feeder system (runners, risers, etc.). By default, it is specified by this formula. Users can

override the default with the process setup option Mass Waste—see [Melting Setup Options](#). Computed mass waste is a function of the following:

- Total gating mass is the mass of that portion of the pouring volume contained in the entire feeder system. It is the product of material density and total gating volume—see Total Gating Volume in [Gating System Model](#).
- Number of cavities (see [Number of Mold Cavities](#))

Mass Bad Parts = Mass Before Machining * (1 / Final Yield - 1)

This is the mass of parts that are scrapped by the current process or by downstream processes, amortized over all the parts in the current production scenario.

- Mass before machining (see formula)
- Final yield (see [Yields for Sand Casting](#))

Non-remeltable Volume = Volume Waste * (1 – Remelt Allowance)

Non-remeltable volume depends on the following:

- Volume Waste: this is Mass Waste (see formula) divided by material density.
- Remelt Allowance: the default remelt allowance is specified by the cost model variable **defaultRemeltAllowanceSandCasting** (1 in starting point VPEs). Users can override the default with the setup option Material Remelt Allowance Percentage.

Non-foundry Yield =

Final Output Volume / (Final Output Volume + Non-foundry Scrap Parts)

Non-foundry yield affects material cost per part. It is the fraction of parts created by this process in the current production scenario that will either survive as good parts once any secondary processes are completed or will be scrapped and remelted. That is, non-foundry yield is the fraction of parts created by this process that are *not* discarded as un-remeltable scrap parts by a downstream process.

Note that scrap parts from downstream, secondary (non-foundry) processes are assumed to be un-remeltable; parts scrapped by foundry processes are assumed to be remelted. The presence of the node attribute **inFoundryProcess** indicates a foundry process.

Non-foundry yield depends on the following:

- Final output volume (product of the annual volume and number of production years, specified in the Production Scenario screen of the Cost Guide)
- Non-foundry scrap parts: number of parts scrapped by downstream, non-foundry processes

Labor and Setup Costs for Sand Casting

All casting processes except Melting use the formulas in this section to determine labor and setup costs. The Melting and Stock Core processes do *not* incur labor or setup costs.

Labor Cost = Labor Time * Labor Rate / Final Yield

Labor cost depends on the following:

- Labor time (see formula below)
- Labor rate (specified as a machine property)
- Final yield (see [Yields](#) for Sand Casting)

Labor Time = (Cycle Time * Number of Operators * Labor Time Standard) + Labor Handling Time

Labor time depends on the following:

- Cycle time (see the process-specific Cycle Time formulas). Note that cycle time is 0 for Stock Core.
- Number of operators (specified as a machine property)
- Labor time standard: specified as the machine property **Labor Time Standard**. This multiplier is used to account for otherwise unaccounted for factors that affect labor time, such as operator fatigue or time spent by the operator for cleaning or maintenance.
- Labor handling time (see below)

Labor Handling Time = Elapsed Handling Time * Number of Handling Operators

This is 0 for automatic moldmaking. For other processes, values for elapsed handling time and number of handling operators are interpolated from values looked up by mass in the lookup table **tblHandlingTimes**. The mass that requires handling varies by process.

For all manual moldmaking processes, the mass that must be handled is Mass Sand per Mold. See [Mold Making](#):

For all refractory coating processes, the following list provides information about the mass that must be handled:

- Manual moldmaking processes: see Mass Sand per Mold in [Mold Making](#). (Since the mass that must be handled is the mass of the sand for the entire mold, labor handling time is amortized over the number of cavities in the mold.)
- Coremaking processes: see Mass Sand per Core in [Coremaking—All Except Stock Core](#) and see [Coremaking--Stock Core](#). (Labor handling time is the sum of the handling times for the cores.)
- Mold Refractory Coating: see Mass Sand per Mold in [Mold Making](#). (Since the mass that must be handled is the mass of the sand for the entire mold, labor handling time is amortized over the number of cavities in the mold.)
- Core refractory coating: see Mass Sand per Core in [Coremaking—All Except Stock Core](#) and see [Coremaking--Stock Core](#). (Labor handling time is the sum of the handling times for the cores.)
- Refractory Coating Air or Oven Dry: see Mass Sand per Mold in [Mold Making](#), see Mass Sand per Core in [Coremaking—All Except Stock Core](#), and see [Coremaking--Stock Core](#). (Labor handling time has two components: mold handling time and core handling time. Mold handling time is amortized over the

- number of cavities in the mold. Core handling time is the sum of the handling times for the air-dried or oven-dried cores.)
- Cleaning: see Mass Before Machining in [Material Cost and Utilization for Sand Casting](#).
 - Finishing: see Mass Before Machining in [Material Cost and Utilization for Sand Casting](#).
 - Shakeout: mass that must be handled is the sum of the following:
 - Mass Before Machining: see [Material Cost and Utilization for Sand Casting](#).
 - Mass Waste: see [Material Cost and Utilization for Sand Casting](#).
 - Mass Sand per Mold: see [Mold Making](#).
 - Mass of the sand in all cores: see Mass Sand per Core in [Coremaking—All Except Stock Core](#). See also [Coremaking--Stock Core](#).
 - Visual Inspection: see Mass Before Machining in [Material Cost and Utilization for Sand Casting](#).

Note that for manual moldmaking, the mass that must be handled includes the sand for the entire mold, so labor handling time is amortized over the number of cavities.

For coremaking processes and Core Refractory Coat, the As with other processes, coremaking and core coating elapsed handling time and number of handling operators are interpolated using **tblHandlingTimes**.

For all processes, the interpolated value is based on the table rows whose **Max Weight** values straddle the mass that must be handled. If the mass falls below the minimum mass listed in the table, the handling time is considered negligible, and is set to 0. If the mass exceeds the maximum mass listed in the table, aPriori uses the values in the row with the maximum mass.

Amortized Batch Setup =
(Setup Time * (Labor Rate + Direct Overhead Rate)) / Batch Size

Batch setup cost per part depends on the following:

- Setup time (specified as the machine property **Setup Time**)
- Labor rate (specified by the machine property **Labor Rate**)
- Direct overhead rate (see [Direct and Indirect Overhead](#))
- Batch size (specified in the **Production Scenario** screen of the Cost Guide)

Melting Formulas for Sand Casting

Melting costs consist of material cost (see [Material Cost and Utilization for Sand Casting](#)), labor cost (see [Labor and Setup Costs for Sand Casting](#) and Cycle Time in this section), direct overhead (see [Direct Overhead](#) in this section), and metal additive cost (see [Additional Direct Costs](#) in this section).

Cycle Time = Process Time * Cycle Time Adjustment Factor

Cycle time is the product of the following:

- Process time (see formula below)

- Cycle time adjustment factor: specified by the cost model variable **cycleTimeAdjustmentFactor**; 1 in aPriori starting point VPEs.

Process Time = Furnace Melting Time / Number of Parts Per Furnace

This is the per-part time to heat the contents of the selected furnace to the pouring temperature. The cost model assumes that the furnace is filled to capacity or nearly to capacity, so as to accommodate the maximal number of parts. Process time depends on the following:

- Furnace melting time (see formula)
- Number of parts per furnace (see formula)

Furnace Melting Time = Furnace Required Energy / Material Transferred Power

This is the time to heat the contents of the selected furnace from ambient temperature to pouring temperature. The cost model assumes that the furnace is filled so as to accommodate the maximal number of parts. Furnace melting time depends on the following:

- Furnace required energy (see formula)
- Material transferred power: this is the rate of heat transfer through the material in the furnace. The cost model calculates this using Fourier's law of heat conduction, assuming a cylindrical furnace whose height is twice its diameter.

Furnace Required Energy = (Furnace Required Heat Energy + Furnace Required Melt Energy + Furnace Required Superheat Energy) * Furnace Factor

This is the energy required to heat the contents of the selected furnace from ambient temperature to pouring temperature. It is the sum of the following:

- Furnace required heat energy (see formula)
- Furnace required melt energy (see formula)
- Furnace required superheat energy (see formula)
- Furnace factor (specified by the machine property **Furnace Factor**)

Furnace Required Heat Energy = Specific Heat Room Temperature * (Solidus Temperature – Ambient Temperature) * Total Required Melted Mass

This is the energy required to heat the contents of the selected furnace from ambient temperature to solidus temperature. It depends on the following:

- Specific heat room temperature (specified by the material property **Specific Heat at Room Temperature**)
- Solidus temperature (specified by the material property **Solidus Temp**)
- Ambient temperature (specified by the cost model variable **ambientTemp**, 21 degrees Celsius in starting point VPEs)
- Total required melted mass (see formula)

Furnace Required Melt Energy = Latent Heat * Total Required Melted Mass

This is the energy required to heat the contents of the selected furnace from solidus temperature to liquidus temperature, (that is, heated so that the entirety of contents is liquid). It is the product of the following:

- Latent heat: Energy per unit mass required to change the selected material completely from solid to liquid, once heated to solidus temperature.
- Total required melted mass (see formula)

Furnace Required Superheat Energy = Specific Heat Solidus Temperature * (Pouring Temperature – Liquidus Temperature) * Total Required Melted Mass

This is the energy required to superheat the contents of the selected furnace from liquidus temperature to pouring temperature. It depends on the following:

- Specific heat solidus temperature (specified by the material property **Specific Heat at Solidus Temperature**)
- Pouring temperature (specified by the material property **Injection Temp**)
- Liquidus temperature (specified by the material property **Liquidus Temp**)
- Total required melted mass (see formula)

Total Required Melted Mass = Number of Parts Per Furnace * Mass Poured

This is the minimum mass of material required to produce the maximum number of parts that can be produced by the selected furnace. It is the product of the following:

- Number of parts per furnace (see formula)
- Mass poured: this is the mass poured per part (see formula).

Number of Parts Per Furnace = rounddown(Furnace Mass Capacity / Mass Poured)

This the maximum number of parts that can be produced by the selected furnace. It depends on the following:

- Furnace mass capacity (product of material density and the machine property **Furnace Capacity**)
- Mass poured: this is the mass poured per part (see formula).

Direct Overhead Cost = (Mass Poured * Melting Rate) / Final Yield

Direct overhead per part depends on the mass poured per part.

Direct overhead depends on the following:

- Mass Poured: mass poured per part (see formula)
- Melting rate: melting cost per unit mass (see formula)
- Final yield (see [Yields for Sand Casting](#))

Mass Poured = Mass Before Machining + Mass Waste + Mass Bad Parts + Mass Loss

Mass poured is the sum of the following:

- Mass before machining (see [Material Cost and Utilization for Sand Casting](#))

- Mass waste (see [Material Cost and Utilization for Sand Casting](#))
- Mass bad parts (see [Material Cost and Utilization for Sand Casting](#))
- Mass loss (see [Material Cost and Utilization for Sand Casting](#))

Melting Rate = Total Annual Factory Cost / Annual Mass Melted Metal

Melting rate depends on the following:

- Total annual factory cost (see formula)
- Annual mass melted metal (see formula)

Total Annual Factory Cost = Annual Labor Cost + Annual Direct Cost + Annual Indirect Cost

Total annual factory cost is the sum of the following:

- Annual labor cost (see formula)
- Annual direct cost (see formula)
- Annual indirect cost (see formula)

Annual Labor Cost = Annual Earned Machine Hours * Number of Operators * Labor Rate

Annual labor cost is the product of the following:

- Annual earned machine hours (see [Annual Earned Machine Hours](#))
- Number of operators (specified by the machine property **Number of Operators**)
- Labor rate: this is the product of the machine property **Labor Rate** and cost model variable **laborRateAdjustmentFactor** (1 in starting point VPEs).

Annual Direct Cost = Depreciation Cost + Maintenance Cost + Annual Energy Cost + Supplies Cost + Imputed Interest Cost

Annual direct cost is the sum of the following:

- Depreciation cost (see [Annual Depreciation](#))
- Maintenance cost (see [Annual Maintenance](#))
- Annual energy cost (see formula)
- Supplies cost (specified by the machine property **Supplies Cost**)
- Imputed interest cost (see [Imputed Interest](#))

Annual Energy Cost = Annual Mass Melted Metal * Melting Cost Per Mass

Annual energy cost is the product of the following:

- Annual mass melted metal (see formula)
- Melting cost per mass (see formula)

Annual Mass Melted Metal = Furnace Productivity * Material Density * Annual Earned Machine Hours

Annual mass melted metal is the product of the following:

- Furnace productivity: this the machine property **Furnace Capacity** divided by the furnace melting time (see formula, above)
- Material density (specified by the material property **Density**)
- Annual earned machine hours (see [Annual Earned Machine Hours](#))

Melting Cost Per Mass = Electricity Rate * Unit Melting Energy

Melting cost per mass is the product of the following:

- Electricity rate (specified by the VPE variable **Electricity Rate**)
- Unit melting energy (see formula)

Unit Melting Energy = (Latent Heat + Specific Heat at Solidus Temperature * (Pouring Temperature - Liquidus Temperature) + Specific Heat at Room Temperature * (Solidus Temperature - Ambient Temperature)) * Furnace Factor

Unit melting energy depends on the following:

- Latent heat (specified by the material property **Heat of Fusion**)
- Specific heat at solidus temperature (specified by the material property **Specific Heat at Solidus Temperature**)
- Pouring temperature (specified by the material property **Injection Temp**)
- Liquidus temperature (specified by the material property **Liquidus Temp**)
- Specific heat at room temperature (specified by the material property **Specific Heat at Room Temperature**)
- Solidus temperature (specified by the material property **Solidus Temp**)
- Ambient temperature (specified by the cost model variable **Ambient Temp**—21 degrees Celsius in starting point VPEs)
- Furnace factor (specified by the machine property **Furnace Factor**)

Annual Indirect Cost = Facility Cost + Support Services Cost

Annual indirect cost is the sum of the following:

- Facility cost (see [Facilities Cost](#))
- Support services cost (see [Support Services Cost](#))

Additional Direct Costs = (Rough Mass * Metal Additive Rate) / Final Yield

Additional direct costs consist of metal additive cost, and is the product of the following:

- Rough mass (see [Material Cost and Utilization for Sand Casting](#))
- Metal additive rate is the cost of metal additive per Kg of rough mass. By default, this is looked up by additive type in the table **tblMetalAdditives**. Additive type is either the additive named **Default** in the lookup table (with a rate of \$0.22 in starting point VPEs), or else the type specified by the user with the **PSO Metal**

Additive Type. You can override the looked-up rate with the **PSO Metal Additive Rate** (see [User Inputs for Sand Casting](#)).

- Final yield (see [Yields for Sand Casting](#))

Degating Formulas

The Degating process uses the formulas below.

Cycle Time = Process Time * Cycle Time Adjustment Factor

Degating cycle time is the product of the following:

- Process time (see formula below)
- Cycle time adjustment factor: specified by the cost model variable **cycleTimeAdjustmentFactor**; 1 in aPriori starting point VPEs.

Process Time = (Total Ingate Area + Riser Base Area) / Degating Feed Rate)

Degating process time depends on the following:

- Total ingate area is the cross-sectional area of an ingate (see the formula for Ingate Area in [Gating System Model](#)) times the number of ingates (see Number of Ingates in [Moldmaking Setup Options](#)).
- Riser base area (see formula)
- Degating feed rate (specified by the machine property **Feed Rate**)

Riser Base Area = Pi * Riser Radius²

Riser base area depends on riser radius, which is half the riser diameter (see formula)

Riser Diameter = (8 * Riser Volume) / Pi)^{1/3}

Because the riser height is assumed to be half the diameter, riser diameter can be determined from riser volume alone.

Cleaning Formulas

The **Cleaning** process uses the formulas below.

Cycle Time = Process Time * Cycle Time Adjustment Factor

Cycle time is the product of the following:

- Process time (see formula below)
- Cycle time adjustment factor: specified by the cost model variable **cycleTimeAdjustmentFactor**; 1 in aPriori starting point VPEs.

Process Time = Blast Time + Reorient Time

The cleaning process time is the sum of the following:

- Blast Time (see formula below)
- Reorient Time. This is 0 for Tumble Blast machines. For Table Blast, Chamber Blast, and Room Blast, this is the product of handling time per operator (elapsed

handling time) and number of handling operators, which are interpolated from values looked up by mass in the lookup table **tblHandlingTimes**. Mass, for these purposes, is Mass Before Machining (see [Material Cost and Utilization for Sand Casting](#)).

Blast Time = (Time per Load / Number of Parts in Load) * Design Complexity Factor

Blast time (formula Tumble Blast Cycle Time, Table Blast Cycle Time, or Room Blast Cycle Time) depends on the following:

- Time per load. For tumble and table blast machines, this is specified by the machine property **Time per Load**. For chamber blast machines, this is specified by the cost model variable **defaultCleaningCycleTime** (4 minutes in starting point VPEs). For Room Blast machines, see the formula below.
- Number of parts per load. For tumble blast and table blast machines, this is the maximum number of parts that fall within the machine's limits for weight and volume (for tumble blast) or for weight and area (for table blast).

For chamber blast machines, in starting point VPEs, this is a half the maximum number of parts that can fit in the chamber. Administrators can customize this fraction (half) with cost model variable **chamberEfficiencyFactor**. The calculation of the number of parts that fit in the chamber assumes a rectangular arrangement and a spacing allowance specified by the cost model variable **chamberCleaningPartDistance** (100mm in starting point VPEs).

For room blast machines, the number of parts is always 1. For more information, see [Cleaning Machine Selection](#).

- Design complexity factor (see [Design Complexity Factor](#))

Time per Load for Room Blast machines = (External Surface Area / External Surface Blast Rate) + (Internal Surface Area / Internal Surface Blast Rate)

For room blast cleaning, process time depends on the following:

- External surface area (area of all surfaces for which there is a non-obstructed **IS_ACCESSIBLE_FROM** relation)
- External surface blast rate (specified by the machine property **External Surface Blast Rate**)
- Internal surface area (area of all surfaces for which there is no non-obstructed **IS_ACCESSIBLE_FROM** relation)
- Internal surface blast rate (specified by the machine property **Internal Surface Blast Rate**)

Additional Direct Costs = Shot Abrasive Cost / Final Yield

Additional direct costs consist of the cost for the abrasive used in the shot stream (including abrasive used for scrapped parts, amortized over all the parts in the current production scenario):

- Shot abrasive cost (see formula below)

- Final yield (see [Yields for Sand Casting](#))

Shot Abrasive Cost = Shot Consumption * Blast Power * Shot Unit Cost * Blast Time

Shot abrasive cost is the product of the following:

- Shot consumption (specified by the machine property **Shot Consumption**)
- Blast power (specified by the machine property **Blast Power**)
- Shot unit cost (specified by the tool shop variable **shotUnitCost**)
- Blast time (see formula above)

Finishing Formulas

The **Finishing** process relies on the formulas below.

Cycle Time = Process Time * Cycle Time Adjustment Factor

Cycle time is the product of the following:

- Process time (see formula below)
- Cycle time adjustment factor: specified by the cost model variable **cycleTimeAdjustmentFactor**; 1 in aPriori starting point VPEs.

Process Time = Grinding Time * Design Complexity Factor

Process time is the product of the following:

- Machine load and unload time (specified as a machine property)
- Grinding time (see formula below)
- Design complexity factor (see [Design Complexity Factor](#))

Grinding Time = (Parting Line Grind Volume / Grinding Speed Parting Line) + ((Ingate Grind Volume + Riser Grind Volume) / Grinding Speed Gating)

Grinding time depends on the following:

- Parting line grind volume (see formula)
- Grinding speed material parting line: this is the product of the machine property **Grinding Speed Parting Line** and an adjustment factor looked up by material cut code in the lookup table **tblGrindingSpeedMaterialFactor**.
- Ingate grind volume (see formula)
- Riser grind volume (see formula)
- Grinding speed material gating: this is the product of the machine property **Grinding Speed Gating** and an adjustment factor looked up by material cut code in the lookup table **tblGrindingSpeedMaterialFactor**.

Parting Line Grind Volume = Parting Line Length To Grind * Parting Line Height * Parting Line Thickness

Parting line grind volume is the product of the following:

- Parting line length to grind (see formula)

- Parting line height. This is interpolated based on values looked up by mass (that is, mass before machining—see [Material Cost and Utilization for Sand Casting](#)) in the table `tblGrindingDimensions`.
- Parting line thickness. This is interpolated based on values looked up by mass (that is, mass before machining—see [Material Cost and Utilization for Sand Casting](#)) in the table `tblGrindingDimensions`.

Parting Line Length to Grind = Parting Line Length * Percent Parting Line to Grind

Parting line length to grind is the product of the following:

- Parting line length (specified by the `length` property of the Parting Line GCD)
- Percent parting line to grind. This is the fraction of the parting line to grind, specified by the setup option `Percent Parting Line to Grind`—1 by default.

Ingate Grind Volume = Total Ingate Area to Grind * Ingate Height

Ingate grind volume is the product of the following:

- Total ingate area to grind (see formula)
- Ingate height. This is interpolated based on values looked up by mass (that is, mass before machining—see [Material Cost and Utilization for Sand Casting](#)) in the table `tblGrindingDimensions`.

Total Ingate Area to Grind = Total Ingate Area * Percent Ingate Area to Grind

Total ingate area to grind is the product of the following:

- Total ingate area is the cross-sectional area of an ingate (see the formula for Ingate Area in [Gating System Model](#)) times the number of ingates (see Number of Ingates in [Moldmaking Setup Options](#)).
- Percent ingate area to grind. This is the fraction of the ingate area to grind, specified by the setup option `Percent Ingate Area to Grind`—1 by default.

Riser Grind Volume = Total Riser Area to Grind * Riser Height to Grind

Riser grind volume is the product of the following:

- Total riser area to grind (see formula)
- Riser height to grind. This is interpolated based on values looked up by mass (that is, mass before machining—see [Material Cost and Utilization for Sand Casting](#)) in the table `tblGrindingDimensions`.

Total Riser Area to Grind = Riser Base Area * Percent Riser Area to Grind

Total riser area to grind is the product of the following:

- Riser base area (see formula)
- Percent riser area to grind. This is the fraction of the riser area to grind, specified by the setup option `Percent Riser Area to Grind`—1 by default.

Riser Base Area = Pi * Riser Radius²

Riser base area depends on riser radius, which is half the riser diameter (see formula)

$$\text{Riser Diameter} = (8 * \text{Riser Volume}) / \text{Pi})^{1/3}$$

Because the riser height is assumed to be half the diameter (see [Gating System Components](#)), riser diameter can be determined from riser volume alone. See the formula for Riser Volume in [Gating System Formulas](#)).

Visual Inspection Formulas

The **Visual Inspection** process relies on the formulas below.

$$\text{Cycle Time} = \text{Process Time} * \text{Cycle Time Adjustment Factor}$$

Cycle time is the product of the following:

- Process time (see formula below)
- Cycle time adjustment factor: specified by the cost model variable `cycleTimeAdjustmentFactor`; 1 in aPriori starting point VPEs.

$$\text{Process Time} = (\text{Internal Examination Time} + \text{External Examination Time}) * \text{Design Complexity Factor} * \text{Core Factor}$$

Process time depends on the following:

- Internal examination time (see formula)
- Internal examination time (see formula)
- Design complexity factor (see [Design Complexity Factor](#))
- Core factor. This is a factor that reflects the extra time required for inspection of parts with cored features. For parts with one cored feature, the factor is specified by the cost model variable `singleCoreInspectionFactor` (1.5 in starting point VPEs); for parts with two or more cored features, the factor is specified by the cost model variable `multiCoreInspectionFactor` (2 in starting point VPEs).

$$\text{Internal Examination Time} = \text{Internal Inspection Rate} * \text{Internal Surface Area}$$

Internal examination time is the product of the following:

- Internal inspection rate: looked up by weight in the lookup table `tblVisualInspection`.

tblVisualInspection		
Max Weight (kg)	Internal Inspection Rate (min / m ²)	External Inspection Rate (min / m ²)
10.00	1.42	1.06
25.00	1.23	0.93
50.00	1.11	0.83
100.00	1.00	0.75
250.00	0.87	0.66
500.00	0.79	0.59
1,000.00	0.71	0.53
2,500.00	0.62	0.46
5,000.00	0.56	0.42
10,000.00	0.50	0.38

- Internal surface area. This is the total area of all internal surfaces. Internal surfaces are those for which there is no **Normal**, **Parallel**, or **Oblique IS_ACCESSIBLE_FROM** relation.

External Examination Time = External Inspection Rate * External Surface Area

External examination time is the product of the following:

- External inspection rate: looked up by weight in the lookup table **tblVisualInspection**.
- External surface area. This is the total area of all external surfaces. External surfaces are those for which there is a **Normal**, **Parallel**, or **Oblique IS_ACCESSIBLE_FROM** relation.

Cope Height

For routings with automatic moldmaking, the height of the cope (the top part of the casting flask) is specified by the machine property **flaskHeight**.

For routings with manual moldmaking, cope height is calculated by the cost model based on part height: it is the smallest multiple of **defaultFlaskHeight** that can accommodate half the part height together with an allowance for extra space (the product of **copeHeightMultiplier** and **sandBorderFlaskBottom**).

Cope height affects tooling costs, gating system design, machine selection, and material utilization.

Design Complexity Factor

A part's design complexity factor is used to calculate process time for Cleaning, Finishing, Shakeout, and Visual Inspection (see [Cleaning Formulas](#), [Finishing Formulas](#), [Shakeout Formulas](#), and [Visual Inspection Formulas](#)). It is a number between the value of the cost model variable **lowComplexityAdjustment** (0.9 in starting point VPEs) and the

value of the cost model variable **extraHighComplexityAdjustment** (1.3 in starting point VPEs).

aPriori determines a part's complexity factor by considering the ratio of the part's surface area to its volume. We refer to a part's surface-area-to-volume ratio as the part's *modulus*.

Modulus of a Part = Part Surface Area / Part Volume

The complexity factor is determined based on an additional ratio: the ratio of the part's modulus to the modulus of a canonical simple part with the same volume. We refer to this ratio as the *modulus ratio*. The greater the modulus ratio, the greater the part complexity.

Modulus Ratio of a Part with Volume V = Part Modulus / Modulus of Canonical Simple Part with Volume V

To serve as canonical simple part with a given volume, V, the cost model uses a cylinder of volume V whose height is equal to its diameter. (The cylinder of a given volume with the smallest surface area is the one whose height equals its diameter.) The diameter of such a cylinder is given by $D = \sqrt[3]{(4V/\pi)}$, and its modulus is 6/D.

The cost model divides possible modulus ratio values into ranges, and associates with each such range a complexity factor range. In starting point VPEs, the association is as follows:

Modulus Ratio Range	Complexity Factor Range
0-0.9	0.9
0.9-1.0	0.9-1.0
1.0-2.5	1.0-1.1
2.5-4.0	1.1-1.2
4.0-10.0	1.2-1.3
≥10.0	1.3

Note that any modulus ratio less than or equal to 0.9 maps to complexity factor 0.9, and any modulus ratio greater than or equal to 10.0 maps to complexity factor 1.3. In other cases, the calculation of the complexity factor involves linear interpolation within these ranges. For example, if the modulus ratio is halfway between the bottom and the top of a modulus ratio range, then the complexity factor lies half way between the bottom and the top of the corresponding complexity factor range.

In general, if the modulus ratio is a certain fraction of the way from the bottom of a modulus ratio range to the top of that range, then the complexity factor is that fraction of the way from the bottom of the corresponding complexity factor range to the top of that range.

The table below summarizes the thresholds that are used to define these ranges. The cost model variables **lowComplexityAdjustment** and **optimumComplexityAdjustment** specify thresholds for both modulus ratios and complexity factors. Note that any modulus ratio

less than or equal to **lowComplexityAdjustment** maps to **lowComplexityAdjustment**, and any modulus ratio greater than or equal to **extraHighModulusRatio** maps to **extraHighComplexityAdjustment**.

Modulus Ratio Threshold		Complexity Factor Threshold	
Cost Model Variable	Starting Point VPE Value	Cost Model Variable	Starting Point VPE Value
lowComplexityAdjustment	0.9	lowComplexityAdjustment	0.9
optimumComplexityAdjustment	1.0	optimumComplexityAdjustment	1.0
mediumModulusRatio	2.5	mediumComplexityAdjustment	1.1
highModulusRatio	4.0	highComplexityAdjustment	1.2
extraHighModulusRatio	10.0	extraHighComplexityAdjustment	1.3

Gating System Model

The properties of the gating system affect material utilization and melting overhead, as well as degating and finishing costs. See the following sections:

- [Material Cost and Utilization for Sand Casting](#)
- [Melting Formulas for Sand Casting](#)
- [Degating Formulas](#)
- [Finishing Formulas](#)

The total volume of the gating system affects material utilization and melting overhead. The cross-sectional area and volume of ingates and risers affect degating and finishing costs. aPriori calculates the volume and cross-sectional areas based on the assumptions described in the following sections:

- [Gating System Components](#)
- [Vertical and Horizontal Systems](#)
- [Choke, Sprue, Runner, and Ingate Area Ratios](#)
- [Pouring Time and Choke Area](#)

See also [Gating System Formulas](#).

Gating System Components

The gating system has the following components:

- Pouring basin (or pouring cup): reservoir into which the molten metal is poured, feeding the *sprue*. The model assumes that the pouring basin volume is the volume of metal that passes in one second, given the optimal pouring time (see [Pouring Time and Choke Area](#)). The model also assumes a box-shaped basin with depth equal to width, and length equal to twice the width.

- Sprue: vertical passage through which the molten metal travels from the pouring basin to the *sprue well*. The model makes the following assumptions about the shape and dimensions of the sprue:
 - Sprue is a tapered cone whose axis is parallel to the direction of metal flow.
 - The cost model assumes bottom gating, so effective height of the sprue is the flask width for vertical systems and the [Cope Height](#) minus half the part height for horizontal systems (see [Vertical and Horizontal Systems](#)). Flask width is specified by machine property **Flask Width**.
 - Sprue top area is the fraction of the sprue bottom area given by the square root of the ratio of the effective sprue height to the pouring basin depth.

$$\text{sprue top area} = \text{sprue bottom area} * \sqrt{\frac{\text{effective sprue height}}{\text{pouring basin depth}}}$$

- Sprue well (or sprue base): reservoir, fed by the sprue, which feeds the *runners*. The model makes the following assumptions about the sprue well shape and dimensions:
 - Cross-sectional area in a plane normal to the direction of metal flow is constant (so the sprue well is cylindrical, for example, or box shaped).
 - Cross-sectional area is 3.5 times that of the sprue bottom, in starting point VPEs. This factor is specified by the cost model variable **sprueWellAreaToWellBase**.
 - Height equals runner height.
- Runners: passages through which the molten metal travels from the sprue well to the *ingates*.
 - In starting point VPEs, the runners are assumed to have a width-to-height ratio of 2. The ratio is specified by the cost model variable **runnerAspectRatio**.
 - For vertical gating systems, runner length is assumed to be twice the [Cope Height](#). For horizontal gating systems, runner length is assumed to be the flask width (specified by the moldmaking machine property **Flask Width**).
 - By default, a single runner is assumed if the mold has a single cavity. For molds with multiple cavities, the default number of runners is half the number of cavities (rounded up to the nearest whole number of runners). Users can specify the number of runners with the setup option **Number of Runners**—see [Moldmaking Setup Options](#).
- Ingates: openings through which the molten metal enters the mold cavity. The model makes the following assumptions about ingates:
 - Each cavity has at least one ingate.
 - There is one ingate for every 6 inches of part length, in starting point VPEs. This distance is specified by the cost model variable **ingateGap**. This is the maximum distance between ingates for a given cavity. You can customize the number of ingates with a setup option—see [Moldmaking Setup Options](#).
 - In starting point VPEs, the ingates are assumed to have a width-to-height ratio of 4. The ratio is specified by the cost model variable **ingateAspectRatio**.

- Length of each is 1/10 of the part length. The fraction of part length is specified by the cost model variable **ingateLengthToPartLength**.
- Top riser: reservoir on top of the mold cavity, initially fed through the riser base from the cavity. During cooling of the metal in the cavity, the riser feeds the cavity to compensate for shrinkage. The model makes the following assumptions about the riser:
 - Riser is a top riser.
 - Riser is cylindrical.
 - Riser is blind, with a firecracker core.
 - Its height is half the diameter of its base.

Vertical and Horizontal Systems

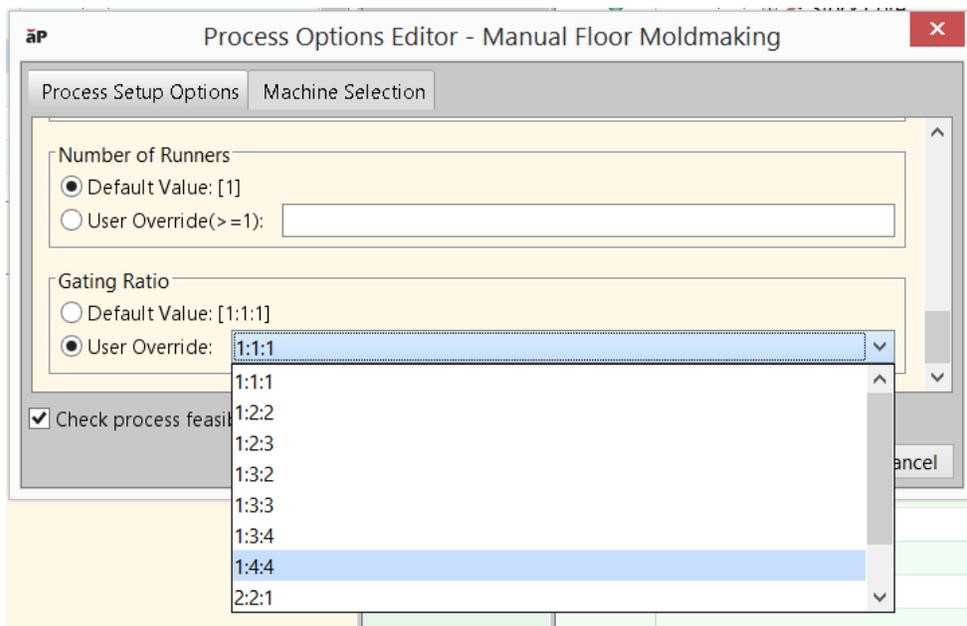
By default in starting point VPEs, the cost model assumes that the gating system is horizontal, unless the moldmaking process is Vertical Automatic. For each moldmaking process, the gating system type is specified by the node attribute **gatingSystem**. In starting point VPEs, Vertical Automatic is the only process for which **gatingSystem** is set to **vertical**; for all other moldmaking processes, it is set to **horizontal**.

Choke, Sprue, Runner, and Ingate Area Ratios

By default, the cost model makes the following assumptions about the cross-sectional areas of the sprue base, runner, and ingates:

- Runner Area = Sprue Base Area
- Ingates Area (that is, sum of the cross-sectional areas of the ingates) = Sprue Base Area.

The setup option **Gating Ratio** allows you to override the default and specify ratios for the cross sectional areas—see [Moldmaking Setup Options](#).



If you specify 1:4:4, for example, the cost model assumes that the sprue base is the choke, and makes the following assumptions about the cross-sectional areas of the sprue base, runner, and ingates:

- Runner Area = 4 * Sprue Base Area
- Ingates Area (that is, sum of the cross-sectional areas of the ingates) = 4 * Sprue Base Area.

The multipliers associated with each ratio are recorded in the lookup table **tblGatingRatios**.

Display Name	Sprue Multiplier	Runner Multiplier	Ingate Multiplier	System Type	Efficiency Coefficient
1:1:1	1.00	1.00	1.00	Naturally pressurized	0.90
1:2:2	1.00	2.00	2.00	Non-pressurized	0.90
1:2:3	1.00	2.00	3.00	Non-pressurized	0.90
1:3:2	1.00	3.00	2.00	Non-pressurized	0.90
1:3:3	1.00	3.00	3.00	Non-pressurized	0.90
1:3:4	1.00	3.00	4.00	Non-pressurized	0.90
1:4:4	1.00	4.00	4.00	Non-pressurized	0.90
2:2:1	2.00	2.00	1.00	Pressurized	0.73
4:4:1	4.00	4.00	1.00	Pressurized	0.73
4:8:3	4.00	8.00	3.00	Pressurized	0.73

Pouring Time and Choke Area

The cost model assumes a pouring time that is optimal for the pouring weight and material (that is, it assumes the fastest pouring rate that is slow enough to avoid oxidation-causing turbulence). The model then derives the choke area from the pouring time, and then uses the assumptions above to derive the component areas from the choke area. The total system volume is derived from the component areas together with the component shape and dimension assumptions above. See [Gating System Formulas](#).

Optimal pouring time is given by the following formula:

$$\text{Optimum Pouring Time} = \text{Pouring Coefficient} * \sqrt{\text{Pouring Weight in lbs}}$$

(Optimal pour time for gray iron uses a different formula—see [Gating System Formulas](#).)

The choke area can be derived from the optimal pouring time with the following formula:

$$\frac{\text{Mass Poured}}{\text{Metal Density} * \text{Optimum Pour Time} * \text{Efficiency Coefficient} * \sqrt{2 * \text{Gravitational Acceleration} * \text{Effective Sprue Height}}}$$

See [Gating System Formulas](#) for more information.

Gating System Formulas for Sand Casting

The gating system is modeled with the following formulas:

**Total Gating Volume = Riser Volume + Runner Volume +
Ingate Volume + Sprue Volume + Sprue Well Volume + Pouring Basin Volume**

The total volume of the gating system is the sum of the following:

- Riser volume (see formula)
- Runner volume (see formula)
- Ingate volume (see formula)
- Sprue volume (see formula)
- Sprue well volume (see formula)
- Pouring basin volume (see formula)

Riser Volume = 1.9 * Shape Factor^{0.7} * Part Volume * Contraction Ratio

This formula is based on the NRL (Naval Research Laboratory) method for determination of riser volume. Riser volume depends on the following:

- Shape factor. This is the ratio of the sum of part length and part width to the maximum thickness of the part (determined by geometry extraction).
- Part volume (determined by geometry extraction)
- Contraction ratio. This is the ratio of the contraction volume percentage for the current material to the contraction volume percentage for steel (looked by material type in the lookup table `tblSolidificationShrinkage`).

Runner Volume = Runner Area * Runner Length * Number of Runners

Runner volume is the product of the following:

- Runner area. This is the cross-sectional area of the runner (see formula).
- Runner length: depends on whether the moldmaking process specifies a horizontal or vertical gating system. The gating system is specified by the moldmaking node attribute `gatingSystem`. In starting point VPEs, Vertical Automatic is the only process for which `gatingSystem` is set to `vertical`; for all other moldmaking processes, it is set to `horizontal`.

For vertical gating systems, runner length is twice the [Cope Height](#).

For horizontal gating systems, runner length is the flask width (specified by the moldmaking machine property `Flask Width`).

- Number of runners. By default, this 1 if the mold has a single cavity; for molds with multiple cavities, the default number of runners is half the number of cavities (rounded up to the nearest whole number of runners). Users can specify the number of runners with the setup option `Number of Runners`.

Runner Area = (Choke Area * Gating Ratio Runner Multiplier) / Number of Runners

Runner area depends on the following:

- Choke area (see formula)

- Gating ratio runner multiplier. This is looked up by gating ratio in the table **tblGatingDesign**. (The gating ratio is 1:1:1 by default, or specified by the setup option **Gating Ratio**--see [Choke, Sprue, Runner, and Ingate Area Ratios](#))
- Number of runners. By default, this is 1 if the mold has a single cavity; for molds with multiple cavities, the default number of runners is half the number of cavities (rounded up to the nearest whole number of runners). Users can specify the number of runners with the setup option **Number of Runners**.

$$\text{Choke Area} = \text{Pour Weight} / (\text{Material Density} * \text{Optimum Pour Time} * \text{Efficiency Coefficient} * \text{Sqrt}(2 * \text{Gravitational Acceleration} * \text{Effective Sprue Height}))$$

Choke area is derived, in part, from the optimum pour time (see [Pouring Time and Choke Area](#)). It depends on the following:

- Pour weight (see formula)
- Material density (specified by the material property **Density**)
- Optimum pour time (see formula)
- Efficiency coefficient. This is looked up by gating ratio in the lookup table **tblGatingRatios**. The gating ratio is 1:1:1 by default, or specified by the setup option **Gating Ratio**--see [Choke, Sprue, Runner, and Ingate Area Ratios](#)).
- Gravitational acceleration (9800 mm/sec²)
- Effective sprue height. This is the flask width for vertical systems and the [Cope Height](#) minus half the part height for horizontal systems (see [Vertical and Horizontal Systems](#)). Flask width is specified by machine property **Flask Width**.

$$\text{Optimum Pour Time} = \text{Pouring Coefficient} * \text{Sqrt}(\text{Pour Weight Lbs})$$

For materials other than gray iron, optimum pour time depends on the following:

- Pouring coefficient. This is looked up in **tblPouringCoefficient** by material and either part maximum thickness or part weight.

Material Name	Min Dim	Max Dim	Coefficient	Dimension	Dimension Unit
Aluminum	0.00	0.25	0.68	thickness	in
Aluminum	0.25	0.44	0.80	thickness	in
Aluminum	0.44	9,999.00	1.43	thickness	in
Ductile Iron	0.00	0.25	1.40	thickness	in
Ductile Iron	0.25	0.75	1.80	thickness	in
Ductile Iron	0.75	3.00	2.00	thickness	in
Ductile Iron	3.00	9,999.00	2.20	thickness	in
Gray Iron	0.00	1,000.00	0.50	weight	lb
Gray Iron	1,000.00	1,000,000.00	0.33	weight	lb
Steel	0.00	100.00	1.20	weight	lb
Steel	100.00	1,000,000.00	0.40	weight	lb

- Pour weight lbs. This is estimated based on material type, part maximum thickness, and number of mold cavities, and converted to pounds—see the formula for Pour Weight.

For gray iron, see the formula below.

$$\text{Gray Iron Optimum Pour Time} = 0.8 * (0.95 + (\text{Part Average Thickness in Inches} / 0.853) * \text{Pour Weight in Lbs}) ^ \text{Exponent}$$

For gray iron, optimum pour time depends on the following:

- Part average thickness in inches (determined by geometry extraction)
- Pour weight lbs. This is estimated based on material type, part maximum thickness, and number of mold cavities, and converted to pounds—see the formula for Pour Weight.
- Exponent. This is ½ for parts weighing less than 1000 pounds, and 1/3 for parts weighing 1000 pounds or more.

$$\text{Pour Weight} = (\text{Mass Poured Per Cavity} * \text{Number of Cavities}) / (\text{Estimated Mold Yield} / 100)$$

Pour weight depends on the following:

- Mass poured per cavity (see formula)
- Number of cavities (see [Number of Mold Cavities](#))
- Estimated mold yield. This is specified by one of the following cost model variables, depending on the current material:
 - **materialYieldDuctile** (for Ductile Iron)
 - **materialYieldSteel** (for Steel or Stainless Steel)
 - **materialYieldAluminum** (for Aluminum or Zinc-Aluminum)
 - **materialYieldZinc** (for Zinc or Lead)

- **materialYieldGray** (for Gray Iron)
- **materialYieldCopper** (for all other materials)

Mass Poured Per Cavity = Volume Before Machining * Material Density

Mass Poured per cavity is the product of the following:

- Volume before machining (see formula)
- Material density (specified by the material property **Density**)

Volume Before Machining = Part Volume + Metal Chip Volume of Machined Features

Volume before machining is the part volume plus the volume removed by machining. It is the sum of the following:

- Part volume (obtained from GCD extraction)
- Metal chip volume of machined features: derived by summing metal chip volume for each machining operation that is applied to the part. For fully-machined features, this calculation is based on feature volume. For machine-finished features, the calculation is based on the area of the finished surface. The calculation assumes that the depth of material removed during finishing is the value specified by the cost model variable **finishAllowance**.

Ingate Volume = Ingate Area * Ingate Length * Number of Ingates

Ingate volume is the product of the following:

- Ingate area (see formula)
- Ingate length (the fraction of part length specified by the cost model variable **ingateLengthToPartLength**—1/10 in starting point VPEs)
- Number of ingates. By default, there is one ingate for every 6 inches of part length, in starting point VPEs. This distance is specified by the cost model variable **ingateGap**. This is the maximum distance between ingates for a given cavity. With the setup option Number of Ingates, you can override the default, and specify the number of ingates explicitly.

Ingate Area = (Choke Area * Gating Ratio Ingate Multiplier) / Number of Ingates

Ingate cross-sectional area depends on the following:

- Choke area (see formula)
- Gating ratio ingate multiplier (looked up by gating ratio in the table **tblGatingRatios**—see [Choke, Sprue, Runner, and Ingate Area Ratios](#))
- Number of ingates (4 times the number of cavities—see [Number of Mold Cavities](#))

Sprue Volume = (PI / 3) * Effective Sprue Height * ((Sprue Bottom Radius^2) + (Sprue Top Radius^2) + (Sprue Bottom Radius * Sprue Top Radius))

Sprue volume depends on the following:

- Effective sprue height. The cost model assumes bottom gating, so this is the flask width for vertical systems and the [Cope Height](#) minus half the part height for horizontal systems (see [Vertical and Horizontal Systems](#)). Flask width is specified by the machine property **Flask Width**.
- Sprue bottom radius (see formula)
- Sprue top radius (see formula)

Sprue Bottom Radius = $\sqrt{\text{Sprue Bottom Area} / \text{PI}}$

Sprue bottom radius is a function of sprue bottom area (see formula).

Sprue Bottom Area = Choke Area * Gating Ratio Sprue Multiplier

Sprue bottom area is the product of the following:

- Choke area (see formula)
- Gating ratio sprue multiplier (looked up by gating ratio in the table [tblGatingRatios](#)—see [Choke, Sprue, Runner, and Ingate Area Ratios](#))

Sprue Top Radius = $\sqrt{\text{Sprue Top Area} / \text{Pi}}$

Sprue top radius depends on sprue top area—see formula.

Sprue Top Area = Sprue Bottom Area * $\sqrt{\text{Effective Sprue Height} / \text{Pouring Basin Depth}}$

Sprue top area depends on the following:

- Sprue bottom area (see formula)
- Effective sprue height: The cost model assumes bottom gating, so this is the flask width for vertical systems and the [Cope Height](#) minus half the part height for horizontal systems (see [Vertical and Horizontal Systems](#)). Flask width is specified by the machine property **Flask Width**.
- Pouring basin depth (see formula)

Pouring Basin Depth = $(\text{Pouring Basin Volume} / 2)^{(1/3)}$

The model assumes a box-shaped basin with depth equal to width, and length equal to twice the width, so depth depends only on volume—see formula.

Pouring Basin Volume = $(\text{Pour Weight} / \text{Metal Density}) / \text{Optimum Pour Time}$

Pouring basin volume is assumed to be the volume of metal that passes in one second, given the optimal pouring time (see [Pouring Time and Choke Area](#)). It depends on the following:

- Pour weight (see formula)
- Metal density (specified by the material property **Density**)
- Optimum pour time (see formula)

Sprue Well Volume = Sprue Well Area * Runner Height

Sprue well volume depends on the following:

- Sprue well area (see formula)

- Runner height (see formula)

Sprue Well Area = Sprue Well Area to Well Base Ratio * Sprue Bottom Area

The cross-sectional area of the sprue well is the product of the following:

- Sprue well area to well base ratio (specified by the cost model variable **sprueWellAreaToWellBase**—3.5 in starting point VPEs)
- Sprue bottom area (see formula)

Runner Height = Sqrt(Runner Area / Runner Aspect Ratio)

Runner height depends on the following:

- Runner area (see formula)
- Runner aspect ratio. This is the ratio of runner width to runner height. It is specified by the cost model variable **runnerAspectRatio** (2 in starting point VPEs).

Mold Making Formulas

The sand casting subprocesses **Horizontal Automatic**, **Vertical Automatic**, **Manual Std Moldmaking**, and **Manual Floor Moldmaking**, and **Manual Pit Moldmaking** rely on the formulas below.

Expendable Tooling Cost = (Sand Cost Per Part + Strainer Cost Per Part) / Final Yield

Expendable tooling cost is a function of the following:

- Sand cost per part (see formula)
- Strainer cost per part (based on the plant variable, **strainerCoreCost** and **Number of Mold Cavities**)
- Final yield (see **Yields** for Sand Casting)

Sand Cost Per Part = (((Mass Sand Per Mold * (1 – Sand Additive Percent)) / Number Of Cavities) * Cost Per Kg Sand) + Sand Additive Cost

Sand cost per part is the cost per part of sand and sand additive. The cost of sand alone is based on the volume of the cope and drag not occupied by parts, cores, the feeder system, or sand additives. Sand cost per part depends on the following:

- Mass sand per mold. This is the mass of sand and sand additive. It is calculated based on the sand density, together with the volume of cope and drag that is not occupied by the parts, cores, or the feeder system. Sand density is obtained by looking up the sand type in the global lookup table **sand**. Sand type is specified by the cost model variable **defaultSandManualStandard**, **defaultSandManualFloor**, or **defaultSandManualPit**.
- Sand additive percent. By default, this is looked up by additive type in the table **tblSandAdditives**. Additive type is either **None** (the default, which indicates that no additive is used), or else the type specified by the user with the PSO **Sand Additive**

Type. You can override the looked-up percent with the PSO **Sand Additive Percent** (see [Melting Setup Options](#)).

- Number of cavities (see [Number of Mold Cavities](#))
- Cost per Kg for sand is obtained by looking up the sand type in the global lookup table **sand**. Sand type is specified by the cost model variable **defaultSandManualStandard**, **defaultSandManualFloor**, or **defaultSandManualPit**.
- Sand additive cost (see formula)

**Sand Additive Cost = Sand Additive Rate * (Sand Additive Percent) *
(Mass Sand per Mold / Number of Cavities)**

Sand additive cost depends on the following:

- Sand additive rate. By default this is looked up by additive type in the table **tblSandAdditives**. Additive type is either **None** (the default, which indicates that no additive is used), or else the type specified by the user with the PSO **Sand Additive Type**. You can override the looked-up rate with the PSO **Sand Additive Rate** (see [Melting Setup Options](#)).
- Sand additive percent. By default, this is looked up by additive type in the table **tblSandAdditives**. Additive type is either **None** (the default, which indicates that no additive is used), or else the type specified by the user with the PSO **Sand Additive Type**. You can override the looked-up percent with the PSO **Sand Additive Percent** (see [Melting Setup Options](#)).
- Mass sand per mold is calculated based on the sand density, together with the volume of the cope and drag that is not occupied by the parts, cores, or risers. Sand density is obtained by looking up the sand type in the global lookup table **sand**. Sand type is specified by the cost model variable **defaultSandManualStandard**, **defaultSandManualFloor**, or **defaultSandManualPit**.
- Number of cavities (see [Number of Mold Cavities](#))

Cycle Time = Process Time * Cycle Time Adjustment Factor

Cycle time is the product of the following:

- Process time (see Automatic Moldmaking Process Time or Manual Moldmaking Process Time below)
- Cycle time adjustment factor: specified by the cost model variable **cycleTimeAdjustmentFactor**; 1 in aPiori starting point VPEs.

Automatic Moldmaking Process Time = (1/Mold Rate) / Number of Cavities

Process time (time per part) is the reciprocal of molding rate (number of molds made per unit time), divided by the number of mold cavities:

- Mold rate (based on the machine property **moldRateNoCore** with adjustments from the machine property **moldRateCoreReduce** if cored features exist)
- Number of cavities (see [Number of Mold Cavities](#))

Manual Moldmaking Process Time = (Mold Rate + Cure Time) / Number of Cavities

Process time (time per part) is the reciprocal of molding rate (number of molds made per unit time), divided by the number of mold cavities:

- Mold rate. This is the mass of sand per mold (see Sand Cost Per Part, above) divided by the sand slinging rate (specified by the cost model variable **sandSlingingRate**), with adjustments using the machine property **moldRateCoreReduce** if cored features exist.
- Cure Time. Specified by the setup option **Sand Cure Time**. The default value is specified by the cost model variable **sandCureTimeManualFloor** (30 minutes in starting point VPEs), **sandCureTimeManualPit** (45 minutes in starting point VPEs), or **sandCureTimeManualStd** (10 minutes in starting point VPEs).
- Number of cavities (see [Number of Mold Cavities](#))

Coremaking—All Except Stock Core

The following sand casting processes rely on the formulas below:

- **CO2 Cured**
- **Hot Box**
- **Isocure Gas**
- **Manual**
- **No Bake**
- **Oil Core**
- **Shell**

See [Coremaking--Stock Core](#) for information on Stock Core expendable tooling.

Each cored feature has one associated coring process per core segment. By default, each cored feature is assumed to have a single-segment core, and so has one associated coring process. For manual coremaking, you can override the default by setting a GCD-specific setup option—see [Customizing the Number of Core Segments](#).

Expendable Tooling Cost = Sand Cost / Final Yield

Expendable tooling cost (per core segment) is a function of the following:

- Sand Cost (see formula)
- Final yield (see [Yields for Sand Casting](#))

Sand Cost =

$$\begin{aligned} & ((\text{Mass Sand per Segment} * (1 - \text{Sand Additive Fraction})) * \\ & (\text{Sand Unit Cost} + \text{Disposal Unit Cost})) + \\ & \text{Sand Additive Cost} \end{aligned}$$

Sand cost per core segment is the cost per segment of sand and sand additive. It depends on the following:

- Mass sand per segment. This is the mass of sand and sand additive. It is calculated based on the sand density, together with the volume of the core (including coreprint volume—see [Coremaking Machine Selection](#)) and the number of core segments. Sand density is obtained by looking up the sand type

in the global lookup table **sand**. Sand type is specified by the toolshop property **coreSandType**.

- Sand additive fraction. By default, this is looked up by additive type in the table **tblSandAdditives**. Additive type is either **None** (the default, which indicates that no additive is used), or else the type specified by the user with the PSO **Sand Additive Type**. You can override the looked-up percent with the PSO **Sand Additive Percent** (see [Melting Setup Options](#)).
- Sand unit cost is obtained by looking up the sand type in the global lookup table **sand**. Sand type is specified by the toolshop property **coreSandType**.
- Disposal unit cost is the cost per kg for sand disposal. It is obtained by looking up the sand type in the global lookup table **sand**. Sand type is specified by the tool shop property **coreSandType**.
- Sand additive cost (see formula)

Sand Additive Cost = Sand Additive Rate * Sand Additive Percent * Mass Sand per Segment

Sand additive cost depends on the following:

- Sand additive rate. By default this is looked up by additive type in the table **tblSandAdditives**. Additive type is either **None** (the default, which indicates that no additive is used), or else the type specified by the user with the PSO **Sand Additive Type**. You can override the looked-up rate with the PSO **Sand Additive Rate** (see [Melting Setup Options](#)).
- Sand additive percent. By default, this is looked up by additive type in the table **tblSandAdditives**. Additive type is either **None** (the default, which indicates that no additive is used), or else the type specified by the user with the PSO **Sand Additive Type**. You can override the looked-up percent with the PSO **Sand Additive Percent** (see [Melting Setup Options](#)).
- Mass sand per segment is calculated based on the sand density, together with the volume of the core (including coreprint volume—see [Coremaking Machine Selection](#)) and the number of core segments. Sand density is obtained by looking up the sand type in the global lookup table **sand**. Sand type is specified by the machine property **Core Sand Type**.

Cycle Time = Process Time * Cycle Time Adjustment Factor

Cycle time is the product of the following:

- Process time (see formula)
- Cycle time adjustment factor: specified by the cost model variable **cycleTimeAdjustmentFactor**; 1 in aPriori starting point VPEs.

Process Time =

Coremaking Time / Number of Corebox Cavities + Core Assembly Time

Process time per core segment is a function of the following:

- Coremaking time: for processes other than Manual Coremaking, this is specified by the machine property **Base Cycle Time**. For Manual Coremaking, see the formula for Manual Coremaking Time, below.
- Number of corebox cavities: if the process setup option **Corebox Cavity Calculation Mode** set to **Opportunistic** (the default setting in starting point VPEs), the number of corebox cavities is the maximum number of cavities that will fit along the length direction of the coremaking machine. If the setup option is set to **Single Cavity**, the number of corebox cavities is 1. The default setup option setting is specified by the cost model variable **coreboxCalcMode** (**Opportunistic** in starting point VPEs). See [Sand Casting Tooling—Core Making](#) for more information.
- Core assembly time: this is 0 for a single-segment core; for a multi-segment core, this is 0 for the first segment and **singleCoreAssemblyTime** (60 seconds in the starting point VPEs) for each of the rest of the segments.

**Manual Coremaking Time =
Sand Resin Mixing Time + Core Box Sand Blowing Time + Core Stripping Time**

For the Manual Coremaking process, coremaking time is the sum of the following:

- Sand resin mixing time: this is the core mass divided by the mixing rate specified by the machine property **Mixing Rate**.
- Core box sand blowing time: this is the time to blow the sand into the corebox. It is the core mass divided by the blowing rate specified by the cost model variable **coreBoxSandBlowingRate** (300 kg/min in starting point VPEs).
- Core stripping time: this is the time for the sand to cure enough to be safely removed from the corebox. It is interpolated from values looked up by blowing time (in minutes) in the lookup table **tblCoreCuring**.

Sand Type	Bench Life Min (min)	Bench Life Max (min)	Stripping Time Min (min)	Stripping Time Max (min)
Acid cure	5.00	10.00	15.00	20.00
Alkyd	10.00	12.00	45.00	60.00
Ester cure	4.00	12.00	10.00	30.00
Furan	7.00	8.00	30.00	40.00
Pepset	2.00	3.00	5.00	7.00

If the sand blowing time is greater than or equal to the table’s largest value for **Bench Life Max**, costing fails for the current GCD.

If the sand blowing time is less than the table’s smallest value for **Bench Life Min**, then core stripping time is the table’s smallest value for **Stripping Time Min**.

If the sand blowing time is between **Bench Life Min** and **Bench Life Max** for some table entry, then core stripping time is between **Stripping Time Min** and **Stripping Time Max** for that entry. In particular, if the blowing time is a certain fraction of the way from **Bench Life Min** to **Bench Life Max**, then the stripping time is that fraction of the way from **Stripping Time Min** to **Stripping Time Max**.

Coremaking--Stock Core

Since stock cores are made by a relatively inexpensive extruder that extrudes a sand mixture through an extruding head, the cost model considers labor and overhead to be negligible for this process. All **Stock Core** costs are in **expendable tooling**.

Expendable Tooling Cost = Aggregated Operation Expendable Tooling / Final Yield

- Sand cost: aggregated from child operations—see formula below.
- Final yield (see [Yields](#) for Sand Casting)

Operation Expendable Tooling = (Stick Expendable Tooling + Stick Labor Cost + Stick Direct Overhead Cost) / Cores Per Stick

Expendable tooling cost depends on the following:

- Stick Expendable Tooling: based on stick volume together with new sand cost per unit mass, sand disposal cost per unit mass, and sand density, listed in the **sand** lookup table by sand type (specified by a machine property), as well as sand additive rate and percent (if applicable--see the PSO Sand Additive Type in [Melting Setup Options](#)) listed in the lookup table `tblSandAdditive`.
- Stick labor cost (see formula below)
- Stick direct overhead cost (see formula below)
- Cores per stick (depends on stock core length and core length)

Stick Labor Cost = Stick Cycle Time * Machine Labor Rate * Machine Operators

Stick labor cost depends on the following:

- Stick cycle time (depends on stock core sticks per hour specified in the Stock Cores lookup table)
- Machine labor rate (specified as a machine property)
- Machine operators (specified as a machine property)

Stick Direct Overhead Cost = Stick Cycle Time * Machine Overhead Rate * Machine Operators

Stick direct overhead cost depends on the following:

- Stick cycle time (depends on stock core sticks per hour specified in the Stock Cores lookup table)
- Machine overhead rate (specified as a machine property)
- Machine operators (specified as a machine property)

Mold Refractory Coat

There is one occurrence of this process for each refractory coating application that the mold receives (see [Number of Coating Applications](#)).

Cycle Time = Process Time * Cycle Time Adjustment Factor

Cycle time is the product of the following:

- Process time (see formula below)
- Cycle time adjustment factor: specified by the cost model variable **cycleTimeAdjustmentFactor**; 1 in aPriori starting point VPEs.

Process Time =
(Total Surface Area / Application Rate per Mold) / Number of Operators

Process time depends on the following:

- Total surface area: this is the area covered by one coat. It is the sum of the **Finished Area** of all the part's surfaces, as well as the **Surface Area** of all the part's voids.
- Application rate: this is looked up by **Application Method** in the lookup table **tblRefractoryCoating**.

Application Method	Application Rate (m ² / min)	Average Output Volume (L / min)
Brushing	0.28	2.00
Flow Coating	3.85	25.00
Spraying	5.13	6.00

The value is converted to square millimeters per second for use in this formula.

- Number of operators: by default, this is specified by the cost model variable **defaultMoldRefractoryCoatingNumOperators**. (1 in starting point VPEs). Users can override the default on a per-part basis with the setup option **Number of Operators**.

Process time is rounded up to a whole number of seconds.

Additional Direct Costs =
(Coating Volume * Refractory Coating Cost * Number of Operators) / Final Yield

Additional direct costs include the cost for the volume of refractory coating material used for one coat of one mold. It depends on the following:

- Coating volume: volume of refractory coating material applied by one operator during the current process. See formula.
- Refractory coating cost: unit cost of coating material, specified by the toolshop variable **refractoryCoatingCost**.
- Number of operators: by default, this is specified by the cost model variable **defaultMoldRefractoryCoatingNumOperators**. (1 in starting point VPEs). Users can override the default on a per-part basis with the setup option **Number of Operators**.
- Final yield (see **Yields for Sand Casting**)

Coating Volume = Process Time * Coating Output Rate

This is the volume of refractory coating material applied to the mold by one operator during the current process. This is the product of the following:

- Process time (see formula)

- Coating output rate: this is the volume per unit time of coating material that is expended during application. It is looked up by [Application Method](#) in the lookup table **tblRefractoryCoating**.

Application Method	Application Rate (m ² / min)	Average Output Volume (L / min)
Brushing	0.28	2.00
Flow Coating	3.85	25.00
Spraying	5.13	6.00

This value is converted to liters per second for use in this formula.

Core Refractory Coat for Sand Casting

This process occurs multiple times in a costing when at least one core receives multiple coats (see [Number of Coating Applications](#)). The number of times the process occurs is the number, N , of coats applied to that core that has the greatest number of coats. There are N instances of Core Refractory Coat, where the i^{th} instance includes the cores that receive at least i coating applications, for all i between 1 and N .

Cycle Time = Process Time * Cycle Time Adjustment Factor

Cycle time is the product of the following:

- Process time: this is the sum of the times required to coat each core that receives a coat in the current instance of this process. (If this is the i^{th} instance, all cores that receive at least i coats are included.) See the formula for **Process Time Core Refractory Coat**, below.
- Cycle time adjustment factor: specified by the cost model variable **cycleTimeAdjustmentFactor**; 1 in aPiori starting point VPEs.

Process Time Core Refractory Coat = (Total Surface Area / Application Rate per Mold) / Number of Operators

This is the time required to apply one coat to the core for a given cored feature. It depends on the following:

- Total surface area: this is the area covered by one coat applied to the core for the given feature. It is 0 the core is not coated. For Voids, it is **Surface Area**. For holes, it is the sum of the values of **Finished Area** for all the feature's descendent surfaces. (Descendent GCDs include children, children's children, and so on, recursively.) For Combo Voids, it is the sum of the values of **Finished Area** for all the feature's descendent surfaces, as well as **Surface Area** for all the feature's descendent voids.
- Application rate: this is looked up by [Application Method](#) in the lookup table **tblRefractoryCoating**.

Application Method	Application Rate (m ² / min)	Average Output Volume (L / min)
Brushing	0.28	2.00
Flow Coating	3.85	25.00
Spraying	5.13	6.00

The value is converted to square millimeters per second for use in this formula.

- Number of operators: by default, this is specified by the cost model variable **defaultMoldRefractoryCoatingNumOperators**. (1 in starting point VPEs). Users can override the default on a per-part GCD with the setup option [Number of Operators](#).

This value is rounded up to a whole number of seconds.

Additional Direct Costs

Additional direct costs include the cost for the volume of refractory coating material used for all cores that receive a coat in the current instance of this process. (If this is the i^{th} instance, all cores that receive at least i coats are included.) See the formula for **Additional Direct Costs Core Refractory Coat**, below.

$$\text{Additional Direct Costs Core Refractory Coat} = (\text{Coating Volume} * \text{Refractory Coating Cost} * \text{Number of Operators}) / \text{Final Yield}$$

This is the cost for the volume of refractory coating material used for one coat of the core for a given coated core. It depends on the following:

- Coating volume: volume of refractory coating material applied to the core by one operator during the current process. See formula.
- Refractory coating cost: unit cost of the coating material, specified by the toolshop variable **refractoryCoatingCost**.
- Number of operators: by default, this is specified by the cost model variable **defaultCoreRefractoryCoatingNumOperators**. (1 in starting point VPEs). Users can override the default on a per-part basis with the setup option [Number of Operators](#).
- Final yield (see [Yields for Sand Casting](#))

Coating Volume = Process Time * Coating Output Rate

This is the volume of refractory coating material applied to the core by one operator during the current process. It is the product of the following:

- Process time (see formula)
- Coating output rate: this is the volume per unit time of coating material that is expended during application. It is looked up by [Application Method](#) in the lookup table **tblRefractoryCoating**.

Application Method	Application Rate (m ² / min)	Average Output Volume (L / min)
Brushing	0.28	2.00
Flow Coating	3.85	25.00
Spraying	5.13	6.00

This value is converted to liters per second for use in this formula.

Refractory Coat Oven Dry for Sand Casting

Coated items (mold and/or cores) that are small enough to fit in some available oven are assumed to be oven dried. So this process is included when at least one coated item fits in an oven (see [Refractory Coat Oven Dry Machine Selection](#)).

This process occurs multiple times in a costing when at least one oven-dried item receives multiple coats (see [Number of Coating Applications](#) and [Number of Coating Applications](#)). The number of times the process occurs is the number, N , of coats applied to that oven-dried mold or core that has the greatest number of coats. The i^{th} instance of the oven-dry process includes the items that receive at least i coating applications, for all i between 1 and N .

Cycle Time = Process Time * Cycle Time Adjustment Factor

Cycle time is the product of the following:

- Process time (see formula below)
- Cycle time adjustment factor: specified by the cost model variable **cycleTimeAdjustmentFactor**; 1 in aPriori starting point VPEs.

Process Time = Oven Dry and Cool Time * Number Oven Cycles Required

This is the time to dry and cool one part's oven-dried items (mold and/or cores). If this is the i^{th} occurrence of Refractory Coat Oven Dry, this is the time to dry and cool those oven-dried items that have at least i coats. Note that the cost model assumes that each oven cycle processes a full load. Process time is the product of the following:

- Oven dry and cool time: this is the time required to dry and cool one machine load of molds and/or cores. By default, it is specified by the cost model variable **defaultOvenDryAndCoolTime** (19 minutes in starting point VPEs). Users can override the default of a per-part basis with the setup option [Oven Dry and Cool Time](#).
- Number of oven cycles required: this is the number of machine loads required to accommodate one part's oven-dried mold and/or cores. This value can be fractional. If this is the i^{th} occurrence of Refractory Coat Oven Dry, only items with at least i coats are included. The machine property **Oven Type** determines whether the number-of-loads calculation is area based (**Conveyor**) or volume based (**Rack**). See the formulas [Number of Oven Cycles Required Area Based](#) and [Number of Oven Cycles Required Volume Based](#), below.

**Number of Oven Cycles Required Area Based =
Total Mold and Core Projected Area /
(Machine Bed Area * Available Oven Spatial Factor)**

For Conveyor machines, the number of required oven cycles depends on the following:

- Total mold and core projected area: this is the total surface area (on the conveyor) occupied by one part's oven-dried items (mold and/or cores). For each item, the surface area occupied is assumed to be the projected area of the item's bounding box. If this is the i^{th} occurrence of Refractory Coat Oven Dry, only items with at least i coats are included.

The cost model assumes that each item lies on the conveyor in the "flattest" orientation (with the shortest dimension vertical). So the projected area of n item's bounding box is the product of the longest two bounding box dimensions (see [Mold and Core Bounding Box Dimensions](#)).

- Machine bed area (product of the machine properties **Bed Length** and **Bed Width**)
- Available oven spatial factor: the cost model assumes that the molds and/or cores in one machine load are arranged so that the total projected area of their bounding boxes is this fraction of machine bed area. The fraction is specified by the square of the cost model variable **defaultRefractoryCoatOvenSpaceAvailableFactor** (0.8 in starting point VPEs). (The cost model variable specifies a linear allowance, so the area allowance is the square of this.)

**Number of Oven Cycles Required Volume Based
Total Mold and Core Volume /
(Machine Bed Volume * Available Oven Spatial Factor)**

For Rack machines, the number of required oven cycles depends on the following:

- Total mold and core volume: this is the total volume occupied by one part's oven-dried mold and cores. For each mold or core, this is the volume of the mold or core's bounding box (see [Mold and Core Bounding Box Dimensions](#)).
- Machine bed volume (product of the machine properties **Bed Length**, **Bed Width**, and **Bed Height**)
- Available oven spatial factor: the cost model assumes that the molds and/or cores in one machine load are arranged so that their bounding boxes occupy this fraction of machine volume. The fraction is specified by the cube of the cost model variable **defaultRefractoryCoatOvenSpaceAvailableFactor** (0.8 in starting point VPEs). (The cost model variable specifies a linear allowance, so the volume allowance is the cube of this.)

Mold and Core Bounding Box Dimensions

Mold bounding box dimensions are taken from the following properties of the moldmaking machine (divided by the number of cavities, if there are multiple cavities):

- **Flask Length**
- **Flask width**
- **Flask Height**

Core bounding box dimensions are specified by the following geometric properties of the cored GCD:

- Simple Hole:
 - **Diameter** (used for two of the three bounding box dimensions)
 - **Length**
- Multistep Hole or Ringed Hole:
 - **Total Length**
 - **Max Diameter** (used for two of the three bounding box dimensions)
- Void or Combo Void:
 - **Box Length**
 - **Box Width**
 - **Box Height**

Refractory Coat Air Dry for Sand Casting

Coated items (mold and/or cores) that are too large to fit in any oven are assumed to be air dried. So this process is included when at least one coated item is too large to fit in any oven (see [Refractory Coat Oven Dry Machine Selection](#)).

This process occurs multiple times in a costing when at least one air-dried item receives multiple coats (see [Number of Coating Applications](#) and [Number of Coating Applications](#)). The number of times the process occurs is the number, N , of coats applied to that air-dried mold or core that has the greatest number of coats. There are N instances of the air-dry process, where the i^{th} instance includes the items that receive at least i coating applications, for all i between 1 and N .

Cycle Time = Air Dry and Cool Time * Cycle Time Adjustment Factor

Cycle time is the product of the following:

- Air dry and cool time: this is the time required to dry the part's mold and/or cores, after one coating application. By default, it is specified by the cost model variable **defaultAirDryAndCoolTime** (60 minutes in starting point VPEs). Users can override the default of a per-part basis with the setup option [Air Dry and Cool Time](#).
- Cycle time adjustment factor: specified by the cost model variable **cycleTimeAdjustmentFactor**; 1 in aPriori starting point VPEs.

Pour Formulas

The sand casting subprocess **Pour** relies on the formulas below.

Cycle Time = Process Time * Cycle Time Adjustment Factor

Cycle time is the product of the following:

- Process time (see formula below)
- Cycle time adjustment factor: specified by the cost model variable **cycleTimeAdjustmentFactor**; 1 in aPriori starting point VPEs.

Process time = Pour Time per Mold / Number of Cavities

Process time includes the time to pour metal into the crucible, move the crucible, and then pour into the mold. It is the product of the following:

- Pour time per mold (see formula below)
- Number of cavities (see [Number of Mold Cavities](#))

Pour Time Per Mold = Material Coefficient * Sqrt(Pounds Poured Per Cavity * Number of Cavities) + Ladle Transport Time + Furnace Tap Time

Mold pour time is a function of the following:

- Material coefficient. Looked up by material type in the lookup table **tblPouringCoefficients**. If the part's average thickness and weight are not within the ranges handled by the lookup table, a value of 1 is used for the coefficient. Similarly, if the part's material is not handled by the lookup table, a value of 1 is used for the coefficient.
- Pounds poured per cavity. This is the Mass Poured as calculated for the Melting process (see [Melting Formulas](#) for Sand Casting) converted to pounds. Note that this quantity is the number of *pounds* poured. The formula implicitly converts this quantity to an equal number of seconds, so that the formula as a whole results in a number of seconds.
- Number of cavities (see [Number of Mold Cavities](#))
- Ladle transport time. By default this is the value of the plant variable **defaultLadleTransportTime** (1 minute in starting point VPEs). Users can override the default with the PSO Ladle Transfer Time—see [Pour Setup Options](#).
- Furnace tap time (see formula below)

Furnace Tap Time = Mass Poured Per Cavity * Number of Cavities / Furnace Tap Rate

Furnace tap time depends on the following:

- Mass poured per cavity. This is the Mass Poured as calculated for the Melting process (see [Melting Formulas](#) for Sand Casting).
- Number of cavities (see [Number of Mold Cavities](#))
- Furnace tap rate (specified by the cost model variable **furnaceTapRate**---121 kg/sec in starting point VPEs)

Cool Formulas

The sand casting subprocess **Cool** relies on the formulas below.

Cycle Time = Process Time * Cycle Time Adjustment Factor

Cycle time is the product of the following:

- Process time (see formula below)
- Cycle time adjustment factor: specified by the cost model variable **cycleTimeAdjustmentFactor**; 1 in aPriori starting point VPEs.

$$\text{Process Time} = \text{Mold Constant} * (\text{Part Volume} / \text{Part Surface Area})^2$$

Process time is calculated using Chvorinov's rule for cooling. It is a function of the following:

- Mold constant (see formula below)
- Part volume (obtained from GCD extraction)
- Part surface area (obtained from GCD extraction)

$$\text{Mold Constant} = \left(\frac{\text{Metal Density} * \text{Heat of Fusion}}{\text{Pour Temperature} - \text{Mold Temperature}} \right)^2 * \left(\frac{\text{Pi}}{4 * \text{Thermal Conductivity of Mold} * \text{Mold Density} * \text{Specific Heat of Mold}} \right) * \left(1 + \frac{\text{Specific Heat of Metal} * (\text{Pour Temperature} - \text{Ejection Temperature})}{\text{Heat of Fusion}} \right)$$

The mold constant depends on properties of the mold and part material, and is independent of part size. The constant is a function of the following:

- Metal density. Specified by the material property **Density**.
- Heat of fusion. Latent heat of fusion of the material. Specified by the material property **Heat of Fusion**.
- Pour temperature. Pour temperature of the material. Specified by the material property **Injection Temp**.
- Melting temperature. Melting or freezing temperature of the material. Specified by the material property **Liquidus Temp**.
- Mold Temperature. Initial temperature of the mold. Specified by the cost model variable **sandMoldTemp** (assumed to be room temperature in starting point VPEs).
- Thermal conductivity of mold. Specified by the cost model variable **sandMoldThermalConductivity** (0.5 Watts per meter per degree Kelvin in starting point VPEs).
- Mold density. Specified by the cost model variable **sandMoldDensity** (1600 kg/m³ in starting point VPEs).
- Specific heat of mold. Specified by the cost model variable **sandMoldSpecificHeat** (1170 Joules per kilogram per degree Kelvin in starting point VPEs).
- Specific heat of metal. Specified by the material property **Specific Heat**.

Shakeout Formulas

The sand casting subprocess **Shakeout** relies on the formulas below.

$$\text{Cycle Time} = \text{Process Time} * \text{Cycle Time Adjustment Factor}$$

Cycle time is the product of the following:

- Process time (see formula below)
- Cycle time adjustment factor: specified by the cost model variable **cycleTimeAdjustmentFactor**; 1 in aPriori starting point VPEs.

$$\text{Process Time} = (\text{Shakeout Time} * \text{Design Complexity Factor}) / \text{Number of Parts}$$

Process time is the product of the following:

- Shakeout time: this is interpolated based on values looked up by rough mass (see [Material Cost and Utilization for Sand Casting](#)) plus core mass in one of the following lookup tables:

- **tblShakeoutTime**, if the machine **Shakeout Type** is **conveyor** or **table**.
- **tblManualShakeoutTime**, if the machine **Shakeout Type** is **manual**.

If the rough mass plus core mass falls outside the range covered by the lookup table, shakeout time is the minimum or maximum time that appears in the table. Note that the looked up value is converted from minutes to seconds for use in this formula.

- Design complexity factor: see [Design Complexity Factor](#).
- Number of parts: this is 1 for machines whose **Shakeout Type** is **manual** or **conveyor**. For machines whose **Shakeout Type** is **table**, this is specified by the setup option [Number of Parts on Shakeout Table](#); by default, it is the maximum number of parts that can fit on the machine--see [Shakeout Machine Selection](#).

Required Clamp Force

Required clamp force affects machine selection for die casting (see [Machine Feasibility and Selection for Sand Casting](#)). It is calculated with the following formula:

$$\text{Required Clamp Force} = \frac{((\text{Parting Line Projected Area} * \text{Number of Cavities}) + \text{Runner Area}) * \text{Material Clamp Force} * \text{Clamp Safety Factor}}{1000}$$

Required clamp force depends on the following factors:

- Parting line projected area (obtained from GCD extraction)
- Number of cavities (see [Number of Mold Cavities](#))
- Runner area (see formula below)
- Clamping force associated with the material
- Clamp safety factor

$$\text{Runner Area} = \text{Number of Cavities} * (\text{Part Length} + \text{Part Width}) * (\text{Maximum Wall Thickness} + 1.5)$$

Runner area depends on the following:

- Number of cavities (see [Number of Mold Cavities](#))
- Part dimensions (obtained from GCD extraction)

Maximum wall thickness (obtained from GCD extraction)

Number of Mold Cavities

The default number of cavities is the maximum number of cavities that can fit on the selected machine, using a layout from the table below (see [Machine Feasibility and Selection for Sand Casting](#))--with the following exceptions:

- Manual Floor Moldmaking routings with large parts (that is, parts whose weight is at or above the value of the cost model variable **largePartThreshold**--1000kg in the starting point VPEs)
- Manual Pit Molding routings

For these routings, the number of cavities always defaults to 1.

For all routings, you can override the default and specify the number of cavities, or request calculation of the number of cavities that minimizes total cost. See [User Inputs](#).

If the user overrides the default, the actual number of cavities is the smallest number of cavities that (i) uses one of the layouts in the table below and (ii) equals or exceeds the number specified by the user or calculated by aPriori. The layouts minimize area for a given number of cavities, and are specified in the lookup table **layoutNumCav**.

Cavities Length Wise	Cavities Width Wise	Number Of Cavities
1	1	1
2	1	2
2	2	4
4	2	8
4	4	16
6	4	24
8	4	32
10	4	40
8	6	48
14	4	56
8	8	64
12	6	72
10	8	80
12	8	96

In order to calculate the number of cavities that minimizes total cost, the cost engine performs a full costing using each layout in the table above, and then chooses the one with the lowest cost.

Calculation of the number of cavities required to meet the specified production volume assumes round-the-clock production and depends on the following:

- Required annual volume
- Plant efficiency
- An estimate of cycle time

Tooling Cost for Sand Casting

Tooling cost appears as **Hard Tooling Cost** in the cost taxonomy under **Capital Costs**.

The following sections describe tooling cost for the various processes and subprocesses:

- Sand Casting Tooling—Mold Making
- Sand Casting Tooling—Core Making

Sand Casting Tooling—Mold Making

The following formulas help determine tooling costs for the processes **Horizontal Automatic**, **Vertical Automatic**, **Manual Std Moldmaking**, and **Manual Floor Moldmaking**:

Tool Cost = (New Tool Cost * Number of New Tools) + (Refurbished Tool Cost * Number of Times to Refurbish)

Tool cost depends on the following:

- New tool cost (see formula below)
- Number of new tools (based on total production volume, pattern material refurbish life, pattern material number of refurbishings per tool, and number of cavities)
- Refurbished tool cost (see formula below)
- Number of time to refurbish (based on total production volume, pattern material refurbish life, pattern material number of refurbishings per tool, and number of cavities)

New Tool Cost = Pattern Cost * Regional Multiplier

New tool cost is the product of the following:

- Pattern cost (based on pattern material costs, machine flask size, part box size, part weight, surface area, number of surfaces, average thickness, max thickness, number of cavities, parting line height and type, and whether cores exist)
- Regional multiplier (specified as a toolshop variable)

Refurbished Tool Cost = New Tool Cost * Pattern Material Refurbish Cost Percent/100

Refurbish tool cost depends on the following:

- New tool cost (see formula above)
- Pattern material refurbish cost percent (specified as a material property)

Sand Casting Tooling—Core Making

This section covers tooling costs for the following coremaking processes:

- CO2 Cured
- Hot Box
- Isocure Gas
- Manual
- No Bake
- Oil Core
- Shell

Tooling cost for a coremaking process is the sum of the costs of the required coreboxes, together with the cost of periodically refurbishing the coreboxes over the course of the current scenario's production period.

To help determine the number of coreboxes that are required, aPriori considers the GCDs that are handled by the process, and forms groups of GCDs of the same shape and size (within a small volumetric error range). At any given time during the production period, GCDs in the same group are assumed to use the same corebox.

The cost model assumes that, over the course of the whole production period, the corebox for each group is refurbished as necessary, until the corebox has been refurbished the maximum number of times, at which point it is replaced with a new corebox.

For a corebox made of a given type of material (specified by the machine property Corebox **Material**), the maximum number of times the corebox can be refurbished is listed by material type in the lookup table **tblCoreboxMaterial**. The table also lists the number of cycles the tool can perform before it must be refurbished.

Corebox Cost Intercept (USD)	Corebox Cost Percent	Corebox Length Allowance (mm)	Corebox Refurb Life	Corebox Refurbs Per Tool	Learning Rate	One Cavity Cost (USD)	Type
920.00	10.00	50.00	5,000.00	5.00	-0.70	920.00	Mahogany
2,300.00	20.00	50.00	1,000,000.00	15.00	-0.70	2,300.00	Cast Iron
3,610.00	20.00	50.00	1,000,000.00	15.00	-0.70	3,610.00	Plastic

Based on the following, aPriori calculates the number of new coreboxes required for a given group:

- Total production volume in the current scenario
- The number of cavities in the corebox
- The number of GCDs in the group
- Number of cycles the corebox can perform before being refurbished (**Corebox Refurb Life** in the table)
- Maximum number of times the corebox can be refurbished (**Corebox Refurbs Per Tool** in the lookup table)

Based on the same information, aPriori calculates the number of times the corebox or coreboxes for a given group are refurbished.

The cost of refurbishing a corebox is determined as a percentage of the cost of a new corebox. The percentage is listed in the lookup table **tblCoreboxMaterial** in the column **Corebox Cost Percent**.

By default, the cost of a single new corebox is calculated based on the corebox material (specified by a toolshop variable) and the number of cavities per corebox (see below). A base cost per cavity is looked up by material type in the lookup table **tblCoreboxMaterial**; the base cost is then adjusted downward according to the number of cavities—the more cavities the lower the cost per cavity, due to the assumed learning curve.

The corebox cost is given by the following formula:

$$\text{Cost} = \text{Number of Cavities} * (\text{Base Cost} * \text{Number of Cavities}^{\text{Learning Rate}})$$

where the learning rate is listed in the lookup table **tblCoreboxMaterial** in the column **Learning Rate**.

Users can override the default at the GCD level with the setup option **Corebox Cost**.

If the process-level setup option Corebox Cavity Calculation Mode is **Opportunistic** (the default setting in starting point VPEs), the number of corebox cavities is the maximum number of cavities that will fit along the length direction of the coremaking machine. This depends on the following:

- GCD dimensions
- GCD properties **Dir CorePrints Box Length**, **Dir Core Prints Box Width**, and **Dir Core Prints Box Height**
- Cost model variable **lengthCorePrint** (10mm in starting point VPEs)
- Cost model variable **coreboxLengthAllowance**, which specifies the corebox wall thickness (19mm in starting point VPEs)
- Machine properties that specify maximum corebox dimensions

See [Coremaking Machine Selection](#) for more information.

If the process setup option Corebox Cavity Calculation Mode is **Single Cavity**, the number of corebox cavities is 1.

User Inputs for Sand Casting

You can control the values listed below by modifying **Process Setup Options**, plant variables, or toolshop variables.

To access **Process Setup Options** for a given process, right click the process in the Manufacturing Process pane, and select **Process Setup Options** from the context menu.

See [Process Defaults and Thresholds for Sand Casting](#) for more information on plant variables.

This section has the following subsections:

- [Top-level Sand Casting Setup Options](#)
- [Melting Setup Options](#)
- [Coremaking Setup Options](#)
- [Moldmaking Setup Options](#)
- [Pour Setup Options](#)
- [Shakeout Setup Options](#)
- [Cleaning Setup Options](#)
- [Refractory Coating Setup Options for Sand Casting](#)
- [Finishing Setup Options](#)
- [Customizing the Number of Core Segments](#)

Top-level Sand Casting Setup Options

Sand Casting provides the following top-level options (defined on the Casting—Sand node):

- **Draft Angle Check:** Draft check settings allow you to determine whether aPriori checks for drafts
- **Minimum Wall Thickness Check:** This option allows you to determine whether aPriori checks minimum wall thickness feasibility.
- **Maximum Wall Thickness Check:** This option allows you to determine whether aPriori checks maximum wall thickness feasibility.
- **Minimum Hole Diameter Check:** This option allows you to determine whether aPriori checks for hole diameters that are too small to cast.
- **Maximum Hole Depth Check:** This option allows you to determine whether aPriori checks for holes that are too deep to cast.
- **Minimum Edge Radius Check:** This option allows you to determine whether aPriori checks for edge radii that are too small to cast.

Melting Setup Options

- **Metal Additive Type:** This PSO is defined for the Melting processes, and allows you to select from among the additive types specified in the lookup table **tblMetalAdditives**. The default additive type is named **Default** in the lookup table.
- **Metal Additive Rate:** This PSO is defined for the Melting process, and allows you to enter the additive cost per unit mass. The default additive rate is looked up by additive type in the lookup table **tblMetalAdditives**. The default additive type is named **Default** in the lookup table, with a rate of \$0.22 per kg in starting point VPEs. See also the **PSO Metal Additive Type**.
- **Mass Waste:** This PSO is defined on the Melting process. Mass waste is the mass of that portion of the pouring volume contained in the feeder system (runners, risers, etc.). By default, it is calculated as described in [Material Cost and Utilization for Sand Casting](#) (see the formula Mass Waste). You can override the default by entering a value in kilograms.
- **Mass Loss:** This PSO is defined on the Melting process. Mass loss is the pouring mass per part of metal that is oxidized or spilled during melting and cannot be remelted. By default, it is calculated as described in [Material Cost and Utilization for Sand Casting](#) (see the formula Mass Loss). You can override the default by entering a value in kilograms.
- This PSO allows you enter the fraction of waste that can be remelted. See [Material Cost and Utilization for Sand Casting](#). By default this is specified by the cost model variable **defaultRemeltAllowanceSandCasting** (1 in starting point VPEs).

Coremaking Setup Options

- **Sand Additive Type:** This PSO is defined for the moldmaking and coremaking processes, and allows you to select from among the additive types specified in the lookup table **tblSandAdditives**. The default additive type is **None**, which indicates that no additive is used.
- **Sand Additive Percent:** This PSO is defined for the moldmaking and coremaking processes, and allows you to enter the percentage of sand that should consist of additive. The default additive percentage is specified in the entry for the current additive type in the lookup table **tblSandAdditives**. The default additive type is **None**, which indicates that no additive is used. See also the **PSO Sand Additive Type**.
- **Sand Additive Rate:** This PSO is defined for the moldmaking and coremaking processes, and allows you to enter the additive cost per unit mass. The default additive rate is specified in the entry for the current additive type in the lookup table **tblSandAdditives**. The default additive type is **None**, which indicates that no additive is used. See also the **PSO Sand Additive Type**.
- **Core Cost:** This PSO is defined for GCDs for which coremaking is performed. You can override the core cost calculated by aPriori, and specify a value explicitly.

- **Corebox Cavity Calculation Mode:** This PSO is defined on the Casting—Sand node. If this is set to **Opportunistic** (the default setting in starting point VPEs), the number of corebox cavities is the maximum number of cavities that will fit along the length direction of the coremaking machine. If set to **Single Cavity**, the number of corebox cavities is 1. The default setting is specified by the cost model variable **coreboxCalcMode** (**Opportunistic** in starting point VPEs). See [Sand Casting Tooling—Core Making](#) for more information.

Moldmaking Setup Options

- **Number of cavities:** By default, the number of mold cavities is the maximum number of cavities that can fit on the selected machine. With this option, you can override the default and specify the number of cavities, or direct aPriori to calculate the number of cavities that minimizes total cost. See [Number of Mold Cavities](#) for more information.
- **Mold Material:** This PSO is defined for the moldmaking processes, and allows you to select from among the mold materials specified by the process's associated tool shop. The default the material is specified by the tool shop field **Default Tool Material Name**. VPE administrators can view and customize these settings. The starting point VPEs use the following defaults:
 - Manual moldmaking: Wood
 - Horizontal Automatic: Cast Aluminum
 - Vertical Automatic: Machined Iron

The starting point VPEs also provide a number of appropriate alternative materials for each moldmaking process.

- **Sand Additive Type:** This PSO is defined for the moldmaking and coremaking processes, and allows you to select from among the additive types specified in the lookup table **tblSandAdditives**. The default additive type is **None**, which indicates that no additive is used.
- **Sand Additive Percent:** This PSO is defined for the moldmaking and coremaking processes, and allows you to enter the percentage of sand that should consist of additive. The default additive percentage is specified in the entry for the current additive type in the lookup table **tblSandAdditives**. The default additive type is **None**, which indicates that no additive is used. See also the **PSO Sand Additive Type**.

Sand Additive Rate: This PSO is defined for the moldmaking and coremaking processes, and allows you to enter the additive cost per unit mass. The default additive rate is specified in the entry for the current additive type in the lookup table **tblSandAdditives**. The default additive type is **None**, which indicates that no additive is used. See also the **PSO Sand Additive Type**.

- **Sand Cure Time:** This PSO is defined for manual moldmaking processes, and allows you to enter the portion of the per-part process time required for curing. The default is specified by the cost model variable **sandCureTimeManualFloor** (30 minutes in starting point VPEs), **sandCureTimeManualPit** (45 minutes in starting point VPEs), or **sandCureTimeManualStd** (10 minutes in starting point VPEs).

- **Number of Ingates:** By default, there is one ingate for every 6 inches of part length, in starting point VPEs. This distance is specified by the cost model variable **ingateGap**. This is the maximum distance between ingates for a given cavity. With this setup option, you can override the default, and specify the number of ingates explicitly. See also [Gating System Components](#).
- **Number of Runners:** By default, a single runner is assumed if the mold has a single cavity. For molds with multiple cavities, the default number of runners is half the number of cavities (rounded up to the nearest whole number of runners). With this setup option, you can override the default and specify the number of runners explicitly. See also [Gating System Components](#).
- **Gating Ratio:** By default, the cost model assumes that cross-sectional area of the sprue base equals that of the runner, and equals the sum of the total cross-sectional area of all the ingates. This setup option allows you to override the default and specify ratios for the cross sectional areas. See [Choke](#), [Sprue](#), [Runner](#), and [Ingate Area Ratios](#) for more information.

Pour Setup Options

- **Ladle Transport Time:** This PSO is defined for the Pour process, and allows you to enter the time in minutes to transport the ladle from furnace to mold. By default it is the value of the plant variable **defaultLadleTransportTime** (1 minute in starting point VPEs).

Shakeout Setup Options

Shakeout provides the following option:

- **Number of Parts on Shakeout Table**

Number of Parts on Shakeout Table

For machines whose **Shakeout Type** is **table**, the default number of parts processed in one machine cycle is the maximum number of parts that can fit on the machine (see [Shakeout Machine Selection](#)). You can override the default, and specify a smaller number with this setup option. Note that the maximum number of parts you can enter is bounded above by the maximum number of parts that can fit on the currently selected machine. See also [Shakeout Formulas](#).

Cleaning Setup Options

Shakeout provides the following option:

- **Number of Blasted Parts**

Number of Blasted Parts

By default, the number of parts in a machine load is determined as described in [Cleaning Formulas](#)—see the formula **Blast Time**. You can override the default, and specify a smaller number with this setup option. Note that the number of parts you enter

is bounded below by the machine property **Min Number Parts**. This setup option is ignored for if the currently selected machine is a room blast machine.

Refractory Coating Setup Options for Sand Casting

The routing node Refractory Coat Mold provides the following option:

- Number of Coating Applications

The process Mold Refractory Coat provides the following option:

- Application Method
- Number of Operators
- Refractory Coating Preparation Time

The Core Refractory Coating operation (under the Core Refractory Coat process) provides the following options:

- Refractory Coating Included
- Application Method
- Number of Coating Applications
- Number of Operators
- Refractory Coating Preparation Time

The processes Refractory Coat Oven Dry and Refractory Coat Air Dry provide the following options:

- Oven Dry and Cool Time
- Air Dry and Cool Time
- Setup Time for the Oven
- Setup Time for Air Drying
- Labor Handling Number of Operators

Number of Coating Applications

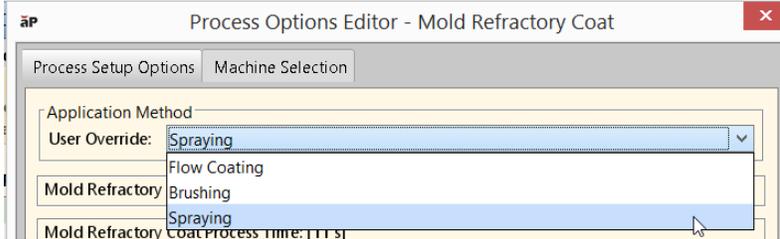
(Provided by the routing node Refractory Coat Mold.)

By default, the number of coating applications for the mold cavities is specified by the cost model variable **defaultNumMoldRefractoryCoatingApplications** (1 in starting point VPEs). With this setup option users can override the default on a per-part basis.

This setup option determines the number of occurrences of the Mold Refractory Coating process. Note that the mold is assumed to be dried after each application. See [Mold Refractory Coat](#).

Application Method

(Provided by the Mold Refractory Coat process.)



By default in starting point VPEs, refractory coating is *sprayed* onto the mold cavities, if they are coated. Administrators can customize the default with the cost model variable **defaultMoldRefractoryCoatingMethod**. With this setup option, users can override the default on a per-part basis.

Application method drives cycle time, which depends on [Number of Coating Applications](#), mold surface area, and application rate. Application rate is looked up by application method in the lookup table **tblRefractoryCoating**.

Application Method	Application Rate (m ² / min)	Average Output Volume (L / min)
Brushing	0.28	2.00
Flow Coating	3.85	25.00
Spraying	5.13	6.00

Application method also drives coating material costs, which is calculated based on output volume per unit time (looked up in **tblRefractoryCoating**) and cost per unit volume (specified by the tool shop variable **Refractory Coating Cost**).

See [Mold Refractory Coat](#) for more information.

Number of Operators

(Provided by the Mold Refractory Coat process.)

By default, the number of operators coating the mold is specified by the cost model variable **defaultMoldRefractoryCoatingNumOperators**. (1 in starting point VPEs). Users can override the default on a per-part basis with this setup option. See also [Mold Refractory Coat](#).

Refractory Coating Preparation Time

(Provided by the Mold Refractory Coat process.)

This is the time to prepare and mix the coating for the mold cavities for one production batch of parts. By default, this is specified by the cost model variable **defaultRefractoryCoatingMoldPreparationTime** (0.25 hours in starting point VPEs). (The use of a slurry mix is assumed by default in starting point VPEs.) With this setup option, users can override the default on a per-part basis.

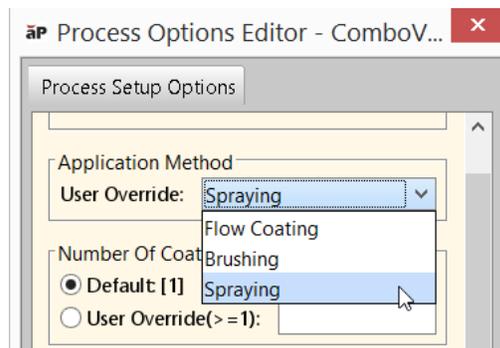
Refractory Coating Included

(Provided by the Core Refractory Coating operations.)

By default in starting point VPEs, cores are assumed to be coated. Administrators can customize the default with the cost model variable **defaultCoreRefractoryCoatingInclusion**. Users can override the default on a per-cored-GCD basis with this setup option.

Application Method

(Provided by the Core Refractory Coating operations.)



By default in starting point VPEs, refractory coating is *sprayed* onto cores. Administrators can customize the default with the cost model variable **defaultCoreRefractoryCoatingMethod**. With this setup option, users can override the default on a per-cored-GCD basis.

Application method drives cycle time, which depends on [Number of Coating Applications](#), core surface area, and application rate. Application rate is looked up by application method in the lookup table **tblRefractoryCoating**.

Application Method	Application Rate (m ² / min)	Average Output Volume (L / min)
Brushing	0.28	2.00
Flow Coating	3.85	25.00
Spraying	5.13	6.00

Application method also drives coating material costs, which is calculated based on output volume per unit time (looked up in **tblRefractoryCoating**) and cost per unit volume (specified by the tool shop variable **Refractory Coating Cost**).

See [Core Refractory Coat for Sand Casting](#) for more information.

Number of Coating Applications

(Provided by the Core Refractory Coating operations.)

By default, the number of coating applications for cores is specified by the cost model variable **defaultNumCoreRefractoryCoatingApplications** (1 in starting point VPEs). With this setup option, users can override the default on a per-cored-GCD basis.

This setup option helps determine the number of occurrences of the Core Refractory Coating process. Note that cores are assumed to be dried after each application.

See [Core Refractory Coat for Sand Casting](#) for more information.

Number of Operators

(Provided by the Core Refractory Coating operations.)

By default, the number of operators coating the core for a given GCD is specified by the cost model variable **defaultCoreRefractoryCoatingNumOperators**. (1 in starting point VPEs). Users can override the default on a per-part basis with this setup option. See also [Core Refractory Coat](#) for Sand Casting.

Refractory Coating Preparation Time

(Provided by the Core Refractory Coating operations.)

This is the batch setup time for coating the specified GCD's cores, that is, the time to prepare and mix the coating for the current GCD's cores for one production batch of parts. By default, this is specified by the cost model variable **defaultRefractoryCoatingCorePreparationTime** (0.25 hours in starting point VPEs). (The use of a slurry mix is assumed by default in starting point VPEs.) With this setup option, users can override the default on a per-cored-GCD basis.

Oven Dry and Cool Time

(Provided by the Refractory Coat Oven Dry process.)

This is the time to oven dry and cool one machine load of molds and/or cores. By default, it is specified by the cost model variable **defaultOvenDryAndCoolTime** (19 minutes in starting point VPEs). Users can override the default with this setup option.

See [Refractory Coat Oven Dry](#) for Sand Casting for more information.

Air Dry and Cool Time

(Provided by the Refractory Coat Air Dry process.)

This is the time to air dry and cool the mold and all cores belonging to one part. By default, it is specified by the cost model variable **defaultAirDryAndCoolTime** (60 minutes in starting point VPEs). Users can override the default with this setup option.

See [Refractory Coat Air Dry](#) for Sand Casting for more information

Setup Time for the Oven

(Provided by the Refractory Coat Oven Dry process.)

This is the time to set up the oven for one production batch of coated, oven-dried molds and cores. If any cores or molds have a second coating then the drying setup is doubled. By default, this is specified by the cost model variable **defaultRefractoryCoatingOvenDryPreparationTime** (0.25 hours in starting point VPEs). With this setup option, users can override the default on a per-part basis.

Setup Time for Air Drying

(Provided by the Refractory Coat Air Dry process.)

This is the time to set up the floorspace for one production batch of coated, oven-dried molds and cores. If any cores or molds have a second coating, the drying setup is

doubled. By default, this is specified by the cost model variable **defaultRefractoryCoatingAirDryPreparationTime** (0.25 hours in starting point VPEs). With this setup option, users can override the default on a per-part basis.

Labor Handling Number of Operators

(Provided by the Refractory Coat Oven Dry and Refractory Coat Air Dry processes.)

This is the number of operators that are assumed to load and unload cores and/or molds for drying. By default, it is specified by the following cost model variables:

- **defaultRefractoryAirDryNumberLaborers** (1 in starting point VPEs)
- **defaultRefractoryOvenDryNumberLaborers** (1 in starting point VPEs)

Finishing Setup Options

- **Percent Parting Line to Grind:** By default, aPriori assumes that finishing is performed on all of the parting line. With this option, you can override the default and specify the percentage of the parting line on which finishing is performed. See also [Finishing Formulas](#).
- **Percent Ingate Area to Grind:** By default, aPriori assumes that finishing is performed on all of the area where the ingate met the part. With this option, you can override the default and specify the percentage of this area on which finishing is performed. See also [Finishing Formulas](#).
- **Percent Riser Area to Grind:** By default, aPriori assumes that finishing is performed on all of the area where the riser met the part. With this option, you can override the default and specify the percentage of this area on which finishing is performed. See also [Finishing Formulas](#).

Process Defaults and Thresholds for Sand Casting

The table below lists some of the important plant variables, together with default values and descriptions.

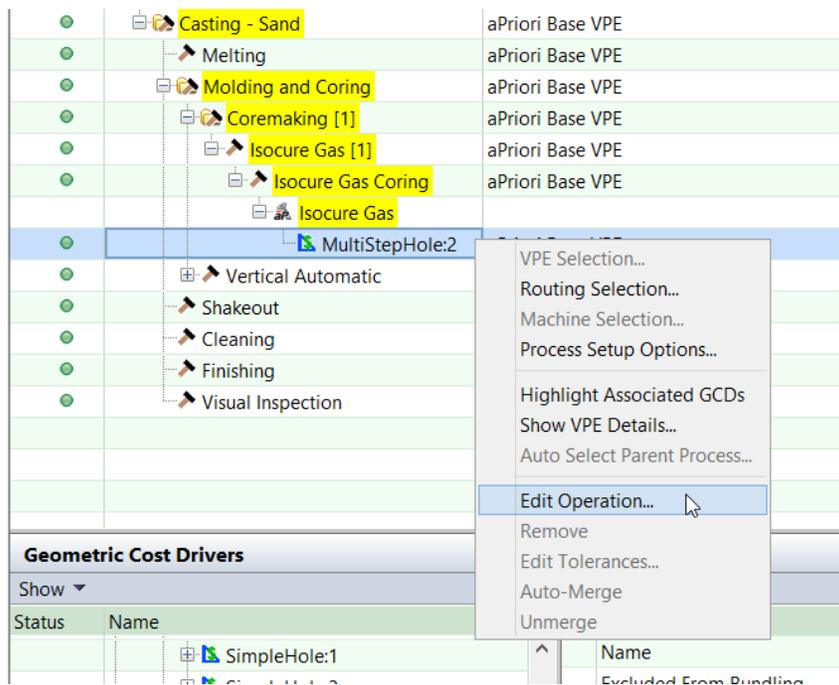
Follow these steps to access plant variables for a given VPE and process:

- 1 Select **Tools > VPE Toolset**, and then click the **Cost Model Workbench** button in the VPE Toolset window.
- 2 Click + to expand the desired VPE in the Open Cost Model window, and then double click the **casting** process group.
- 3 In the Cost Model Workbench, click + to expand **Global Cost Model Information**, and then double click **Cost Model Variables**.

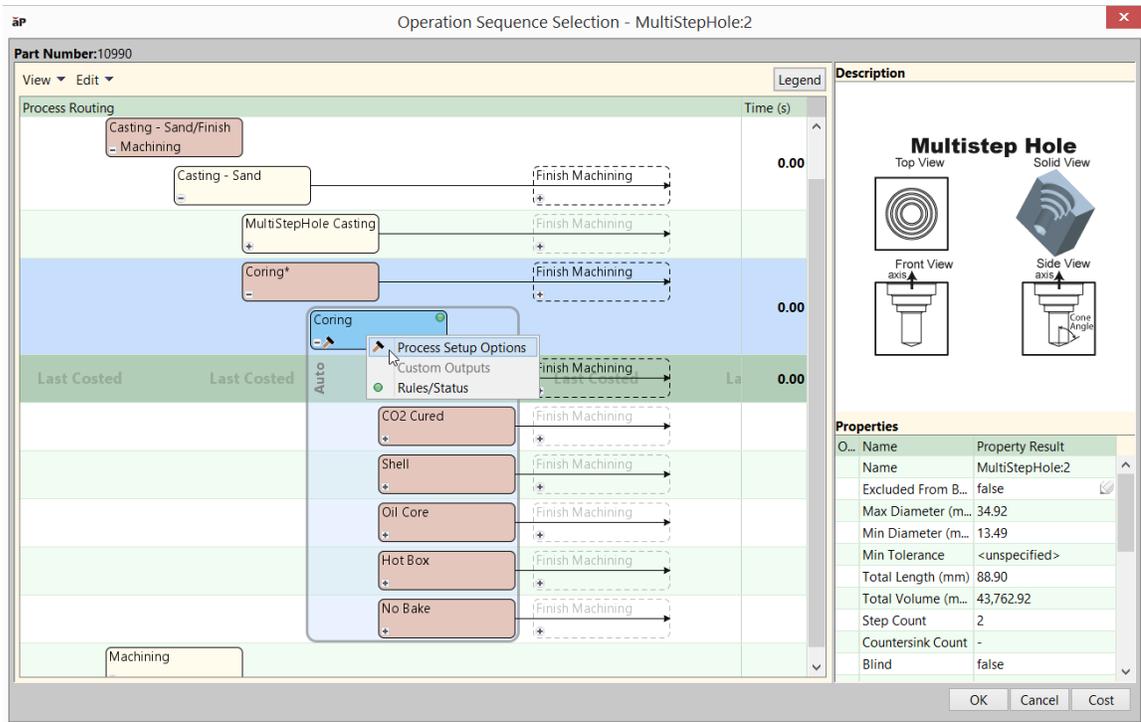
Customizing the Number of Core Segments

Sand casting manual moldmaking routings allow you to customize the number of core segments for a given cored feature. By default, each cored feature is assumed to have a single-segment core, and so has one associated coring operation. For manual coremaking, you can override the default with a GCD-specific setup option. Follow these steps:

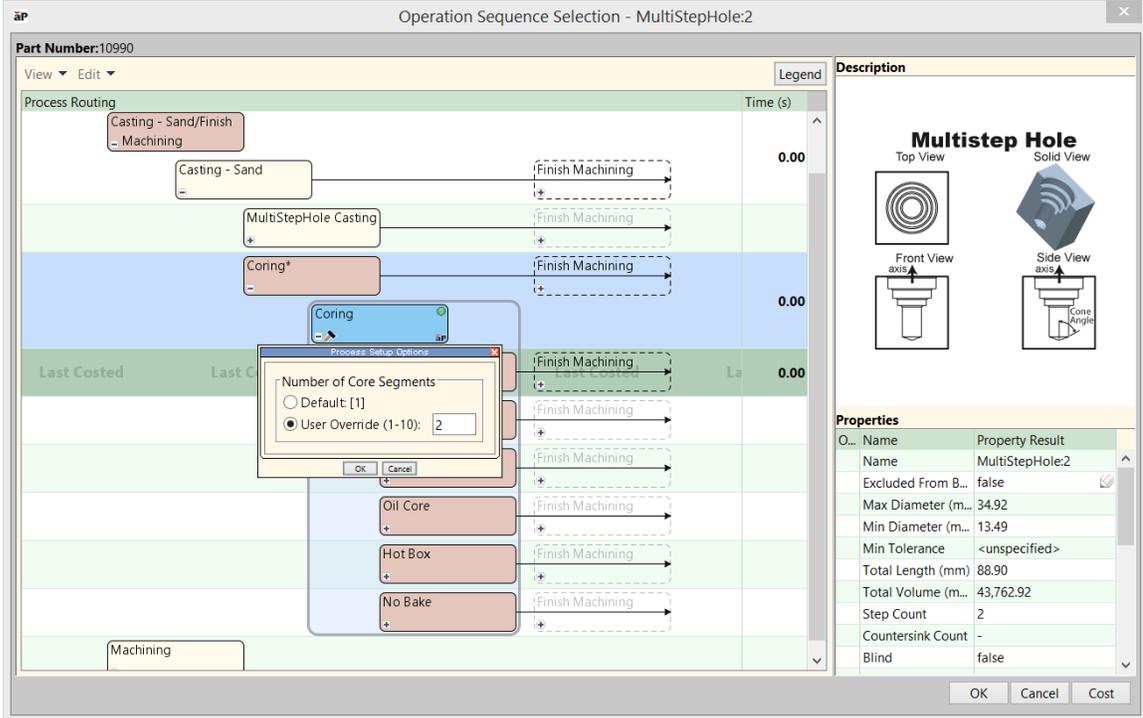
- 1 Right click the cored feature in the Manufacturing Process Pane or the Geometric Cost Drivers Pane, and select **Edit Operation**:



- 2 In the Operation Sequence Selection dialog, right click the Coring operation, and select Process Setup Options:



- 3 Enter the number of core segments. The value you enter cannot exceed 10. The segments are assumed to be all of equal size.



Material Utilization Variable

Variable Name	Description
finishAllowance	See Material Cost and Utilization for Sand Casting and Gating System Formulas.

Design Complexity Variables

Variable Name	Description
highComplexityAdjustment	See Design Complexity Factor.
highComplexityModulus	See Design Complexity Factor.
optimumModulus	See Design Complexity Factor.

Hole Feasibility Variable

Variable Name	Description
minSandCastableHoleDiameter	See Feasibility and Routing for Sand Casting and Part Geometry for Sand Casting.

Machine Selection Variable

Variable Name	Description
usePreferredMachines	See Machine Feasibility and Selection for Sand Casting .

Melting Variable

Variable Name	Description
metalAdditiveRate	Cost per kg of metal in sand casting to account for metal additives.

Moldmaking Variables

Variable Name	Description
defaultSandManualFloor	Plant default for sand: 'chemBond' or 'greenSand' used in Manual Floor moldmaking
defaultSandManualPit	Plant default for sand: 'chemBond' or 'greenSand' used in Manual Pit moldmaking
defaultSandManualStandard	Plant default for sand: 'chemBond' or 'greenSand' used in Manual Standard moldmaking
furnaceTapRate	See the formula for Furnace Tap Time in Pour .
strainerCoreCost	Cost of strainer per part (used in Expendable Tooling Cost)
Max Complexity Multiplier Scrap	Good Part Yield: Multiplier for maximum value of complexity
Num Core Coefficient	Good Part Yield: Effect of number of cores
Num Surface Coefficient	Good Part Yield: Effect of number of surfaces
Material Yield Ductile	Material Yield: Baseline percent material yield for ductile iron
Material Yield Steel	Material Yield: Baseline percent material yield for steel
Material Yield Copper	Material Yield: Baseline percent material yield for coppers and bronzes

Material Yield Aluminum	Material Yield: Baseline percent material yield for aluminum
Material Yield Zinc	Material Yield: Baseline percent material yield for zinc
Material Yield Gray	Material Yield: Baseline percent material yield for gray cast iron
Num Cavities Material Yield Add	Material Yield: Additional percent per cavity
Cavity Ceiling	Material Yield: Maximum additional percent yield for cavity consideration
largePartThreshold	Threshold at which a part is considered too large to support multiple cavities or parts per mold. See Number of Mold Cavities . Exceeding this threshold also triggers inclusion of Degating in the current routing. See Sand Casting Process-level Routing .
Low End Thickness	Material Yield: Used to access multiplier for chunkiness.
High End Thickness	Material Yield: Used to access multiplier for chunkiness
Low end Multiplier	Material Yield: Lowest multiplier for chunkiness
High End Multiplier	Material Yield: Highest multiplier for chunkiness
sandCureTimeManualFloor	See the formula for Moldmaking Process Time in Mold Making .
sandCureTimeManualPit	See the formula for Moldmaking Process Time in Mold Making .
sandCureTimeManualStd	See the formula for Moldmaking Process Time in Mold Making .
sandMoldDensity	See Cool .
sandMoldSpecificHeat	See Cool .
sandMoldThermalConductivity	See Cool .
sandSlingingRate	See Mold Making .

Coremaking Variables

Variable Name	Description
---------------	-------------

coreboxCalcMode	See Sand Casting Tooling—Core Making.
coreBoxSandBlowingRate	See Coremaking—All Except Stock Core
coreboxToolingCalc	See Sand Casting Tooling—Core Making.
coreboxLengthAllowance	See Coremaking Machine Selection and Sand Casting Tooling—Core Making
coreDiameterPlay	Available stock core diameters must be within this margin of the actual feature diameter. See Stock Core Feasibility.
lengthCorePrint	See Coremaking Machine Selection and Sand Casting Tooling—Core Making
minSandCastableHoleDiameter	See Coremaking Feasibility and Routing for Sand Casting
maxCoreAspectRatio	See Coremaking Feasibility and Routing for Sand Casting
maxWeightHotBoxCore	See Coremaking Feasibility and Routing for Sand Casting.
maxWeightGasCore	See Coremaking Feasibility and Routing for Sand Casting.
maxWeightGasCuredCore	See Coremaking Feasibility and Routing for Sand Casting.
maxWeightShellCore	See Coremaking Feasibility and Routing for Sand Casting.
regionalMultiplier (toolshop variable)	See Sand Casting Tooling—Core Making

Gating System Variables

Variable Name	Description
sprueWellAreaToWellBase	Ratio of sprue well cross-sectional area to well base cross-sectional area. See Gating System Components.
runnerAspectRatio	Runner width-to-length ratio. See Gating System Components.
ingateGap	See Gating System Components.

ingateAspectRatio	Ingate width-to-length ratio. See Gating System Components .
ingateLengthToPartLength	Ingate length is this fraction of the part length. See Gating System Components .
materialYieldDuctile	Estimated mold yield for Ductile Iron. See the formula for Pour Weight in Gating System Formulas .
materialYieldSteel	Estimated mold yield for Steel or Stainless Steel. See the formula for Pour Weight in Gating System Formulas .
materialYieldAluminum	Estimated mold yield for Aluminum or Zinc-Aluminum. See the formula for Pour Weight in Gating System Formulas .
materialYieldZinc	Estimated mold yield for Zinc or Lead. See the formula for Pour Weight in Gating System Formulas .
materialYieldGray	Estimated mold yield for Gray Iron. See the formula for Pour Weight in Gating System Formulas .
materialYieldCopper	Estimated mold yield for Copper and various other materials. See the formula for Pour Weight in Gating System Formulas .

Refractory Coating Variables

Variable Name	Description
defaultAirDryAndCoolTime	See Air Dry and Cool Time .
defaultCoreRefractoryCoatingInclusion	See Refractory Coating Included .
defaultCoreRefractoryCoatingMethod	See Application Method .
defaultCoreRefractoryCoatingNumOperators	See Number of Operators .
defaultMoldRefractoryCoatingMethod	See Application Method .
defaultMoldRefractoryCoatingNumOperators	See Number of Operators .
defaultNumCoreRefractoryCoatingApplications	See Number of Coating Applications .
defaultNumMoldRefractoryCoatingApplications	See Number of Coating Applications .
defaultOvenDryAndCoolTime	See Oven Dry and Cool Time .

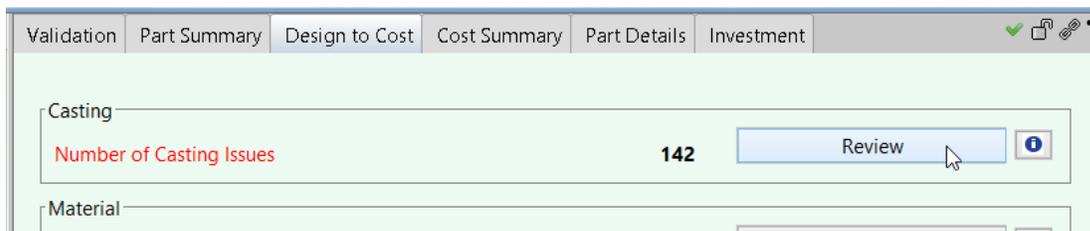
defaultRefractoryAirDryNumberLaborers	See Labor Handling Number of Operators.
defaultRefractoryCoatOvenSpaceAvailableFactor	See Oven Dry and Cool Time and Air Dry and Cool Time.
defaultRefractoryCoatingAirDryPreparationTime	See Setup Time for Air Drying.
defaultRefractoryCoatingCorePreparationTime	See Refractory Coating Preparation Time.
defaultRefractoryCoatingMoldPreparationTime	See Refractory Coating Preparation Time.
defaultRefractoryCoatingOvenDryPreparationTime	See Setup Time for the Oven.
defaultRefractoryOvenDryNumberLaborers	See Labor Handling Number of Operators.

Visual Inspection Variables

Variable Name	Description
multiCoreInspectionFactor	See Visual Inspection Formulas.
singleCoreInspectionFactor	See Visual Inspection Formulas.

Design-to-cost Configuration for Sand Casting

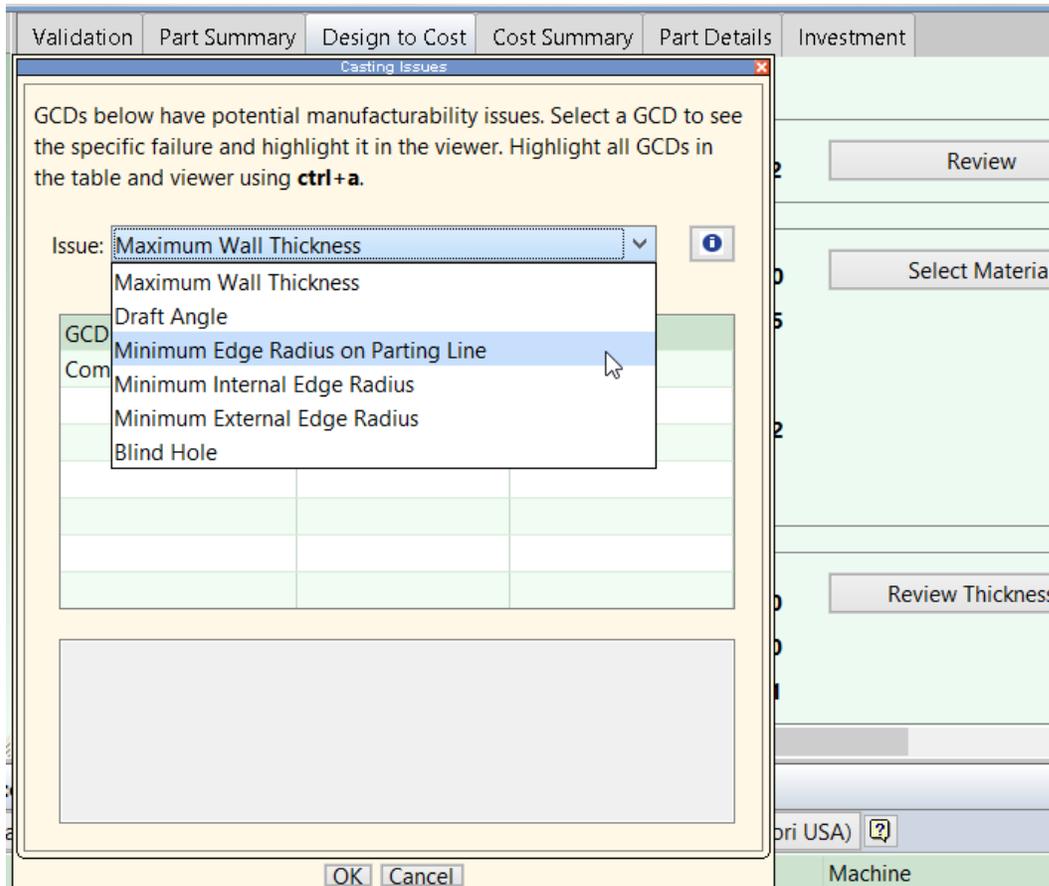
This section covers configuring Design to Cost for the Casting—Die and Casting—Sand process groups. You can configure some of the thresholds that help determine what plastic Issues and thickness violations are listed in the Design to Cost tab.



The following sections cover lookup tables that specify thresholds related to plastic issues (Material Issues, Draft Issues, and Radii Issues):

- Material Issues: Wall Thickness Thresholds
- Draft Issues: Draft Angle Thresholds
- Radius Issues: Edge Radius Thresholds

- Proximity Issues: Hole Proximity Issues
- Hole Issues: Maximum Hole Depth
- Hole Issues: Minimum Hole Diameter



A lookup table related to tolerance and roughness thresholds is covered in [Tolerance Grade and Roughness Ranges](#).



Material Issues: Wall Thickness Thresholds

The lookup table `tblWallThickness` specifies the recommended minimum and maximum wall thickness for each process and material.

Material Type	Maximum Wall Thickness (mm)	Minimum Wall Thickness (mm)	Process Name
Aluminum	38.10	0.50	High Pressure Die Casting
Aluminum	50.50	2.00	Gravity Die Casting
Aluminum	1,016.00	3.00	Sand Casting
Aluminum Bronze	38.10	1.00	High Pressure Die Casting
Aluminum Bronze	50.50	3.00	Gravity Die Casting
Aluminum Bronze	1,016.00	3.00	Sand Casting
Brass	38.10	1.00	High Pressure Die Casting
Brass	50.50	3.00	Gravity Die Casting
Brass	1,016.00	2.30	Sand Casting
Bronze	38.10	1.00	High Pressure Die Casting
Bronze	50.50	3.00	Gravity Die Casting
Bronze	1,016.00	2.30	Sand Casting

If the thickness of some portion of a part's wall falls outside of this range, a corresponding Material Issue is listed under Plastic Issues.

In addition, the Thickness panel of the Design to Cost tab displays the Recommended Maximum and Minimum thicknesses.

Thickness

Maximum and minimum recommended thicknesses vary by material and manufacturing process. Select an option below in **Thicknesses To Show** and click **Show Thicknesses** to highlight the areas of the part that are in violation of the recommended thicknesses.

	Current	Recommended
Maximum (mm)	56.807	38.100
Minimum (mm)	14.305	0.500
Max:Min Ratio	3.971	1.000

Thicknesses To Show

100% - 150% of Recommended Max (1)
 Max (mm):

Manual Input
 Min (mm):

If the view does not update, it is likely because there are no thicknesses within the selected range

Draft Issues: Draft Angle Thresholds

The lookup table `tblDraftAngle` specifies the minimum recommended draft angle for each material and process.

tblDraftAngle		
Material Type	Min Draft Angle (deg)	Process Name
Aluminum	0.25	High Pressure Die Casting
Aluminum	0.50	Gravity Die Casting
Aluminum	0.50	Sand Casting
Aluminum Bronze	0.25	High Pressure Die Casting
Aluminum Bronze	0.50	Gravity Die Casting
Aluminum Bronze	0.50	Sand Casting
Brass	0.50	Gravity Die Casting
Brass	0.50	Sand Casting
Brass	0.70	High Pressure Die Casting
Bronze	0.50	Gravity Die Casting
Bronze	0.50	Sand Casting
Bronze	0.70	High Pressure Die Casting
Copper	0.50	Gravity Die Casting

If the draft angle of some feature is less than the relevant minimum, a corresponding Draft Issue is listed under Casting Issues.

Radius Issues: Edge Radius Thresholds

The lookup table **tblMinEdgeRadius** specifies the minimum recommended internal and external edge radius for each material and process.

tblMinEdgeRadius			
Material Type	Min External Radii (mm)	Min Internal Radii (mm)	Process Name
Aluminum	0.30	3.00	Sand Casting
Aluminum	0.50	0.25	High Pressure Die Casting
Aluminum	6.00	2.00	Gravity Die Casting
Aluminum Bronze	0.30	3.00	Sand Casting
Aluminum Bronze	1.00	0.50	High Pressure Die Casting
Aluminum Bronze	9.00	3.00	Gravity Die Casting
Brass	0.23	2.30	Sand Casting
Brass	1.00	0.50	High Pressure Die Casting
Brass	9.00	3.00	Gravity Die Casting
Bronze	0.23	2.30	Sand Casting
Bronze	1.00	0.50	High Pressure Die Casting
Bronze	9.00	3.00	Gravity Die Casting
Copper	0.23	2.30	Sand Casting

If the radius of some edge is less than the relevant minimum, a corresponding Radius Issue is listed under Casting Issues. Note that sharp edges on the parting line are listed separately, since only those that *partially* lie on the parting line are likely to present an issue.

Proximity Issues: Hole Proximity Issues

The recommended minimum distance between a hole and another feature is one of the following (depending on the current process):

- Sand Casting: the first Minimum Wall Thickness value that appears in the lookup table **tblWallThickness** for Sand Casting and the current material type.
- Gravity Die Casting: the first Minimum Wall Thickness value that appears in the lookup table **tblWallThickness** for Gravity Die Casting and the current material type.
- High Pressure Die Casting: this value is interpolated from values in the lookup table **tblHighPressureDieCastingHoleProximity**, and is bounded above and below the largest and smallest distances in the table. The lookup is keyed by the diameter of the hole. For the minimum recommended distance between two holes, the lookup is keyed by the diameter of the larger-diameter hole.

tblHighPressureDieCastingHoleProximity		
Process Name	Hole Diameter (mm)	Minimum Distance (mm)
High Pressure Die Casting	2.00	0.41
High Pressure Die Casting	2.50	0.55
High Pressure Die Casting	3.00	0.61
High Pressure Die Casting	3.50	0.74
High Pressure Die Casting	4.00	0.86
High Pressure Die Casting	4.50	0.92
High Pressure Die Casting	5.00	0.98
High Pressure Die Casting	6.00	1.23
High Pressure Die Casting	6.30	1.23
High Pressure Die Casting	7.00	1.23
High Pressure Die Casting	8.00	1.53
High Pressure Die Casting	10.00	1.84
High Pressure Die Casting	12.00	2.15

Hole Issues: Maximum Hole Depth

The maximum recommended hole depth for a given diameter is looked up by diameter, material type, and process in the lookup table **tblMaxHoleDepth**.

aP <i>tblMaxHoleDepth</i> ✕			
Hole Diameter (mm)	Hole Max Depth (mm)	Material Type	Process Name
2.40	2.96	Brass	High Pressure Die Casting
2.40	2.96	Bronze	High Pressure Die Casting
2.40	2.96	Copper	High Pressure Die Casting
2.40	2.96	Manganese Bronze	High Pressure Die Casting
2.40	2.96	Silicon Brass	High Pressure Die Casting
2.40	5.97	Aluminum	High Pressure Die Casting
2.40	5.97	Aluminum Bronze	High Pressure Die Casting
2.40	5.97	Magnesium	High Pressure Die Casting
2.40	7.10	Lead	High Pressure Die Casting
2.40	7.10	Zinc	High Pressure Die Casting
2.40	7.10	Zinc-Aluminum	High Pressure Die Casting
3.18	4.76	Brass	High Pressure Die Casting
3.18	4.76	Bronze	High Pressure Die Casting
3.18	4.76	Copper	High Pressure Die Casting
3.18	4.76	Manganese Bronze	High Pressure Die Casting

If the depth of some hole is greater than the relevant maximum, or if the lookup cannot be performed because the diameter is out of range for the lookup table, a corresponding Hole Issue is listed under Casting Issues.

Hole Issues: Minimum Hole Diameter

The minimum recommended hole diameter is looked up by material type and process in the lookup table *tblMinHoleDiameter*.

aP <i>tblMinHoleDiameter</i> ✕		
Material Type	Min Hole Diameter (mm)	Process Name
Aluminum	2.40	High Pressure Die Casting
Aluminum	4.80	Gravity Die Casting
Aluminum	4.80	Sand Casting
Aluminum Bronze	2.40	High Pressure Die Casting
Aluminum Bronze	4.80	Gravity Die Casting
Aluminum Bronze	4.80	Sand Casting
Brass	4.80	Gravity Die Casting
Brass	4.80	High Pressure Die Casting
Brass	4.80	Sand Casting
Bronze	4.80	Gravity Die Casting
Bronze	4.80	High Pressure Die Casting
Bronze	4.80	Sand Casting
Copper	4.80	Gravity Die Casting

If the diameter of some hole is less than the relevant minimum, a corresponding Hole Issue is listed under Casting Issues.

Tolerance Grade and Roughness Ranges

The lookup table **tblGtolProcessCapabilities** lists the geometric tolerance grade and roughness ranges achievable by a given process for a given type of tolerance/roughness. A tolerance grade range together with a feature size determines a literal tolerance range. See the section “How aPiori calculates achievable tolerance ranges” in the *aPiori Professional User Guide*.

Process	Gtol Category	Capability System	Best Achievable	Worst Achievable	Num Repetitions
3D Laser	angularity	IT	10	16	1.00
3D Laser	bendAngleTolerance	IT	10	16	1.00
3D Laser	circularity	IT	10	16	1.00
3D Laser	concentricity	IT	10	16	1.00
3D Laser	cylindricity	IT	10	16	1.00
3D Laser	diamTolerance	IT	10	16	1.00
3D Laser	flatness	IT	10	16	1.00
3D Laser	parallelism	IT	10	16	1.00
3D Laser	perpendicularity	IT	10	16	1.00
3D Laser	positionTolerance	IT	10	16	1.00

In addition to affecting cycle times of secondary machining operations, the ranges affect what operations are listed as tolerance-driven machining operations and what operations are listed as special finishing operations. See the Tolerances and Finishing Operations section of the Design to Cost tab.

8 Composites Process Group

This chapter describes the costing details and inputs that are available for the Composites process group. With this group, aPiori estimates times and costs for the manufacture of aerospace parts, including aircraft components such as those for the wings, fuselage, and nacelles.

This chapter has the following sections:

- Composites Cost Model Overview
 - GCD Extraction for Composites
 - Routing and Feasibility for Composites
 - Machine Selection for Composites
 - Cost Algorithms and Calculations for Composites
 - User Inputs for Composites
-

Composites Cost Model Overview

This Overview has the following sections:

- Composites General Process
- Part Geometry for Composites
- Materials for Composites
- Machines for Composites
- Tooling for Composites

Composites General Process

The Composites process group provides three alternative processes that model the process of laying up plies onto a mold:

- Hand layup (default layup process): plies are laid up by one or more operators. For some parts, one or more cores are placed between ply layers. Multiple layers are laid up, and debulking (using a vacuum bag) is performed periodically, between layers. Setup options allow you to control when the first debulking occurs and how often subsequent debulks occur.

In addition to layup and debulking costs, the model for this process also includes costs for a vacuum drop test and for attaching thermocouples in preparation for autoclave curing.

The model calculates layup times from area-based layup rates that take into account the complexity of each ply. For parts with cores, the model includes potting costs for core regions that contain fastener holes. A setup option allows you to specify the number of fastener holes in the part (0, by default). The model also includes costs for core splicing, if necessary. A setup option allows you to specify the total length of the joints formed by core splicing for the part (also 0, by default).

- Automated Fiber Placement (AFP): plies are laid up by a machine that uses spools of relatively narrow ply material (1/8"-1/2"). The cost model assumes that cores are *not* used with AFP. In addition to layup costs, the model for this process also includes programming costs, as well as costs for a vacuum drop test and for attaching thermocouples in preparation for autoclave curing.

The model calculates layup times from area-based layup rates that take into account the complexity of each ply. Layup times are also driven by the number of active machine spools. Setup options allow you to specify programming cost, as well as to override the calculated number of active spools.

- Automated Tape Layup (ATL): plies are laid up by a machine that uses spools of relatively wide ply material (6"-12"). The cost model assumes that cores are *not* used with ATL. In addition to layup costs, the model for this process also includes programming costs, as well as costs for a vacuum drop test and for attaching thermocouples in preparation for autoclave curing.

The model calculates layup times from area-based layup rates that take into account the complexity of each ply.

Hand layup is included by default in the routing for a Composites part. Users can manually include AFP or ATL instead. All three layup processes take into account tooling and materials costs—see [Tooling for Composites](#) and [Materials for Composites](#).

Note: In the Composites interface and in this documentation, “mold” and “tool” generally refer to the same thing: the mold onto which plies are laid.

The process group also provides processes that model cutting plies from a roll (prior to hand layup), cleaning and preparing the mold, curing the part, removing the part from the mold, and inspecting the part:

- Ultrasonic Cut: accounts for costs associated with unrolling, cutting, and splicing (if necessary) material in order to assemble ply kits for hand layup. It also accounts for indenting and unloading plies.

Cutting time calculations are perimeter based. Cutting rate is taken from a machine property or setup option. Plies are assumed to be cut one at a time, by default, but a setup option allows you to specify the number of plies stacked up in order to be cut all at once. Cutting rate is adjusted when plies are stacked.

- **Tool Clean:** accounts for costs associated with manual, laser, or cryogenic cleaning of the mold. For manual cleaning, the cost model also accounts for the cost of cleaning agent. The clean time calculation is area based.
- **Mold Preparation:** accounts for costs associated with applying and curing some number of coats of mold release material, as well as costs associated with applying and curing tack. A setup option allows you to specify the number of mold-release coats. You can manually exclude tackifier application and curing.

Times are calculated based on mold area, as are consumable material costs for mold release and tackifier.

- **Autoclave Cure:** accounts for costs associated with attaching and detaching thermocouples, loading and unloading the part, and curing the part with heat and pressure in an autoclave. A setup option allows you to specify that multiple parts cannot share the autoclave machine during a cycle, which affects overhead calculations. Multiple parts are assumed, by default, if they can fit in the machine.
- **Bench Operation: Tool Breakdown:** accounts for costs associated with moving the part and tooling into the work cell, removing the vacuum bag, removing the part from the tool, and moving the empty tooling out of the work cell.

Moving and part-removal times are based on part and tool dimensions. A setup option allows you to override the calculated part removal time. Vacuum bag removal time is based on part perimeter.

- **Bench Operation: Final Inspection:** accounts for costs associated with visually inspecting the finished part. Times are calculated based on part surface area.

These processes are followed by secondary processes, including Milling (on a 5-Axis Mill), Ultrasonic Scanning (C-Scan or A-Scan), and Manual Paint.

See [Routing and Feasibility for Composites](#) for more information.

Part Geometry for Composites

Geometry extraction for Composites parts recognizes some Composites-specific GCDs: **Ply GCD** and **Core GCD**. In addition, the **Component GCD** has several properties that are process-group-specific or have process-group-specific meanings.

Some of the Ply and Core properties are extracted from CAD file metadata (for example, the **Material Name**, **Orientation**, and **Sequence** for a given ply). A *Composites Mapping File* allows aPriori to convert the metadata into GCD property values that can be used by the cost model. The default mapping file supports CAD files that contain published Fibersim or CPD ply design data. The Mapping File is a fully customizable XSLT file. If you need to support additional metadata formats, contact aPriori Professional Services.

Materials for Composites

A composite part potentially uses multiple different types of material, since different plies or cores in the same part might use different material types. The name of the material used by a given ply or core is extracted from CAD file metadata, and that name is established as the value of the GCD property **Material Name**.

Because of this, when you cost a composite part, you don't select a material in the Material Selection dialog. Instead, aPriori extracts the material type for each ply and core, and the cost model looks up material properties by material type in the material table for the current VPE.

Note that aPriori converts the CAD file metadata into GCD property values with the help of a *Composites mapping file*. The default mapping file supports CAD files that contain published Fibersim or CPD ply design data. The mapping file is a fully customizable XSLT file. If you need to support additional metadata formats, contact aPriori Professional Services.

Important ply material properties include the following:

- Deformation Average Angle: used to help determine layup speed for Ply Placing operations.
- Material Cost per Area: drives material costs.
- Material Utilization: drives materials costs, as well as machine selection and setup costs for Ultrasonic Cut.
- Material Width: drives times, costs and machine selection for automated layup processes as well as for Ultrasonic Cut.

Primary ID Name	Other			Process Parameters										Can AFP	Can ATL	Can HLU		
	Material Fo...	Density (kg...																
Copper - Expanded Metal Foil - 36in	Ply	1,383.85														false	false	true
Epoxy - Adhesive Flim - 36in	Ply	1,383.85														false	false	true
Carbon - Tow Prepreg - 1/2in	Ply	1,174.79														true	false	false
Carbon - Tow Prepreg - 1/4in	Ply	1,174.79														true	false	false
Carbon - Tow Prepreg - 1/8in	Ply	1,174.79														true	false	false
Carbon - Uni Directional Prepreg Tape - 6in	Ply	790.89														false	true	true
Carbon - Uni Directional Prepreg Tape - 12in	Ply	790.89														false	true	true
Carbon - Uni Directional Prepreg Tape - 24in	Ply	790.89														false	true	true
Carbon - NCF Prepreg - 4 Layer	Ply	790.85														false	false	true
Carbon - Woven Prepreg - Plain Weave 3K	Ply	723.66														false	false	true
Glass - Woven Prepreg - Plain Weave 3K	Ply	723.66														false	false	true
Carbon - Woven Prepreg - 8 Harness 3K	Ply	693.74														false	false	true
Glass - Woven Prepreg - 8 Harness 3K	Ply	693.74														false	false	true
Carbon - Woven Prepreg - 5 Harness 3K	Ply	688.91														false	false	true
Generic Ply Material	Ply	688.91														false	false	true
Glass - Woven Prepreg - 5 Harness 3K	Ply	688.91														false	false	true
Aluminium- Honeycomb Core - 1/8in Cell	Core	354.04																
Aluminium- Honeycomb Core - 3/16in Cell	Core	49.60																
Aluminium- Honeycomb Core - 3/8in Cell	Core	48.06																
Aramid- Honeycomb Core - 1/8in Cell	Core	48.00																
Aramid- Honeycomb Core - 3/16in Cell	Core	48.00																
Generic Core Material	Core	48.00																
Aramid- Honeycomb Core - 3/4in Cell	Core	48.00																

Machines for Composites

Starting point VPEs provide the following machines:

- Virtual Hand Layup machines that represent ISO 7 clean rooms. They are provided with a range sizes, and with and without support for laser-projected layup guides:

Primary ID	Direct Overhead Rate (USD / hr)
Name	
Clean Room Space with Laser Projection - 16m x 4m	137.88
Clean Room Space - 16m x 4m	127.69
Clean Room Space with Laser Projection - 8m x 4m	68.94
Clean Room Space - 8m x 4m	68.84
Clean Room Space with Laser Projection - 4m x 4m	34.36
Clean Room Space - 4m x 4m	31.92
Clean Room Space with Laser Projection - 2m x 2m	10.41
Clean Room Space - 2m x 2m	7.98

- Automated Fiber Placement machines, with a range of sizes:

Primary ID	Accounting
Name	Direct Overhead Rate (USD / hr)
MTorres TORRESFIBERLAYUP - 12.1m x 2.4m x 2.4m	333.28
Automated Fiber Placement Machine - 18m x 8m x 8m	324.02
Fives Cincinnati Viper 6000 - 18m x 8m x 8m	324.02
Automated Fiber Placement Machine - 11.4m x 4.2m x 4.2m	228.36
Coriolis C2 - 10m x 4.5m x 4.5m	199.43
Fives Cincinnati Viper 4000 - 13.5m x 6m x 6m	156.65
Electroimpact AFP Machine - 10m x 3.6m x 3.6m	150.75
Mikrosam Discovery - 2m x 1m x 1m	34.36
Automated Fiber Placement Machine - 2m x 1m x 1m	34.32

- Automated Tape Layup machines, with a range of sizes:

Primary ID	Direct Overhead Rate (USD / hr)
Name	
Automated Tape Layup Machine - 33m x 6.5m x 3m	327.58
Forest-Line ATLAS Access - 32.5m x 6.5m x 1.2m	325.35
Microsam Taurus - 30m x 6m x 6m	316.22
Forest-Line ATLAS One - 20m x 4m x 1m	268.15
MTorres Layup 3D - 18m x 7.8m x 1.7m	260.62
Fives Cincinnati Charger ATL - 16m x 7m x 1.2m	246.95
Automated Tape Layup Machine - 16m x 5.3m x 1.6m	240.57
MTorres Layup 3D - 12.5m x 5.4m x 1.7m	219.04
Microsam Libra - 12m x 2.5m x 2.5m	212.79
Fives Cincinnati Charger SFTL - 8m x 3.2m x 0.15m	170.81
Fives Cincinnati Charger SFTL - 6m x 1.4m x 0.15m	140.54
Automated Tape Layup Machine - 5m x 1.9m x 1m	127.69
Microsam Discovery - 2m x 1m x 1m	34.83

- Ultrasonic Cut machines in a variety of sizes:

Primary ID	...	...	Rates
Name	...	...	Cut Rate (mm / min)
American GFM US 120 - 3m x 1.8m	...	...	2,000.00
Bullmer Premiumcut ELC CV - 1.2m x 1.6m	...	...	2,000.00
Bullmer Premiumcut ELC CV - 2m x 1.8m	...	...	2,000.00
Bullmer Premiumcut ELC CV - 3.2m x 1.8m	...	...	2,000.00
Bullmer Premiumcut ELC single ply cutter - 3.2m x 2.8m	...	...	2,000.00
Bullmer Turbocut D2501 CV - 1.8m x 1.8m	...	...	1,666.00
Bullmer Turbocut D2501 CV - 2.5m x 1.8m	...	...	1,666.00
Ultrasonic Cutter - 3.1m x 2.1m	...	...	1,600.00
Gunnar Novex L - 1.9m x 1.8m	...	...	1,500.00
Gunnar Novex S - 1.9m x 1.3m	...	...	1,500.00
Ultrasonic Cutter - 2.5m x 1.8m	...	...	1,400.00
Zund G3 L 3200 standard - 3.2m x 1.8m	...	...	1,400.00
Zund G3 L2500 standard - 2.5m x 1.8m	...	...	1,400.00
Zund G3 L2500 variant - 2.5m x 1.8m	...	...	1,400.00
Zund G3 L3200 variant - 3.2m x 1.8m	...	...	1,400.00
Ultrasonic Cutter - 1.7m x 1.6m	...	...	1,300.00
Gerber DCS1500 - 1.5m x 1.8m	...	...	1,100.00
Gerber DCS1600 - 1.8m x 1.5m	...	...	1,100.00
Gerber DCS2500 - 2.8m x 1.8m	...	...	1,100.00
Gerber DCS2500 - 6.5m x 1.8m	...	...	1,100.00
Gerber DCS2600 - 2.8m x 1.8m	...	...	1,100.00
Gerber DCS2600 - 6.5m x 1.8m	...	...	1,100.00
Gerber Z1 1.8 long - 3m x 1.8m	...	...	1,100.00
Gerber Z1 1.8 standard - 1.8m x 1.8m	...	...	1,100.00
Gerber Z1 2.54 - 3m x 2.5m	...	...	1,100.00
Ultrasonic Cutter - 6.5m x 1.8m	...	...	1,100.00
American GFM CM10 - 1.8m x 1.8m	...	...	1,000.00
Gunnar Gunnar AiOX Composites XL - 1.6m x 1.2m	...	...	800.00

Mold Preparation

virtual machines, which represent work areas in a range of sizes:

Primary ID
Name
Mold Preparation Area 16m x 4m
Mold Preparation Area 2m x 2m
Mold Preparation Area 4m x 4m
Mold Preparation Area 8m x 4m

- Autoclave Cure machines:

Primary ID	Name	...	Direct Overhead Rate (USD / hr)
	ASC Process Systems EC 3m x 12.2m	...	154.19
	Autoclave 3m x 12.2m	...	153.99
	American Autoclave 3m x 6.1m	...	115.19
	Autoclave 3m x 6.1m	...	91.56
	Thermal Equipment Coroporation 3m x 6.1m	...	91.35
	ASC Process Systems EC 3m x 6.1m	...	77.14
	ASC Process Systems EC 0.9m x 1.5m	...	16.79
	Autoclave 0.9m x 1.5m	...	16.67

- Bench Operation virtual machines, which represent work areas in a range of sizes:

Primary ID	Name
	Manual Bench Cell - 16m x 4m
	Manual Bench Cell - 2m x 2m
	Manual Bench Cell - 4m x 4m
	Manual Bench Cell - 8m x 4m

- Tool Clean machines, which represent a work area (for manual cleaning) or a combination of a work area and a laser or cryogenic cleaning device:

Primary ID	...	...	Rates
Name	...	...	Clean Rate (mm ² / s)
Tool Clean Area: Adapt 1000W Laser - 16m x 4m	...	...	3,330.00
Tool Clean Area: Cold Jet Cryogenic - 16m x 4m	...	...	3,330.00
Tool Clean Area: Adapt 600W Laser - 8m x 4m	...	...	2,780.00
Tool Clean Area: Cold Jet Cryogenic - 8m x 4m	...	...	2,780.00
Tool Clean Area: Adapt 500W Laser - 4m x 4m	...	...	2,220.00
Tool Clean Area: Cold Jet Cryogenic - 4m x 4m	...	...	2,220.00
Tool Clean Area: Adapt 300W Laser - 2m x 2m	...	...	1,390.00
Tool Clean Area: Cold Jet Cryogenic - 2m x 2m	...	...	1,390.00
Tool Clean Area: Manual - 16m x 4m	...	...	0.00
Tool Clean Area: Manual - 2m x 2m	...	...	0.00
Tool Clean Area: Manual - 4m x 4m	...	...	0.00
Tool Clean Area: Manual - 8m x 4m	...	...	0.00

See also Machine Selection for Composites.

Tooling for Composites

By default, hard tooling cost is calculated based on the following:

- Tool material cost: looked up by the current tool material (see [Layup Tool Material for Hand Layup](#), [Layup Tool Material for ATL](#), and [Layup Tool Material for AFP](#)) in the **Layup Tool Cost Per Area** column of the tool shop **Tool Materials** table:

Tool Materials		
Edit ▼		
Name	Layup Tool Cost Per Area (USD / m ²)	Material Type Name
Aluminium	15,500.00	Aluminum
Invar	44,476.00	Nickel Alloy
Steel	23,250.00	Steel

- Tool surface area (see Tool Length, Width, and Area)
- Tool shop variable **Region Multiplier**.

Each layup process provides a setup option that allows users to override the default on a per-part basis, and specify the tool cost explicitly:

- Hand Layup: Layup Tool Cost Override
- Automated Tape Layup: Layup Tool Cost Override
- Automated Fiber Placement: Layup Tool Cost Override

GCD Extraction for Composites

Geometry extraction for Composites parts recognizes some Composites-specific GCDs: Ply GCD and Core GCD. In addition, the Component GCD has several properties that are process-group-specific or have process-group-specific meanings.

Some of the Ply and Core properties are extracted from CAD file metadata (for example, the **Material Name**, **Orientation**, and **Sequence** for a given ply). A *Composites mapping file* allows aPriori to convert the metadata into GCD property values that can be used by the cost model. The default mapping file supports CAD files that contain published Fibersim or CPD ply design data. The mapping file is a fully customizable XSLT file. If you need to support additional metadata formats, contact aPriori Professional Services.

Component GCD

Important properties of the Component GCD include the following:

- Perimeter: total length of the part's external and internal contours.
- External Perimeter: total length of the part's external contour.
- Surface Area: surface area of the part.

Ply GCD

Important properties of the Ply GCD include the following:

- Length and Width: this is determined based on the smallest rectangle that (a) encloses the flattened ply, and (b) has a side aligned with the ply's fiber direction. In particular, ply Length is the length of a side of this rectangle that is aligned with the ply's fiber direction, and ply Width is the length of a side of this rectangle that is perpendicular to the play's fiber direction.

- **Surface Area:** surface area of one side of the flattened ply. This does not include the area of cutouts.
- **Surface Area Filled:** area of the flattened ply's convex hull. The convex hull is the region that would be enclosed by a string pulled taught around the edges of the ply; it is the smallest convex region that encloses the flattened ply.

The area of this region approximates the area of the ply prior to the removal of cutouts. It helps determine ply layup rate. See [Ply Placing Operation for Hand Layup](#), [Ply Placing Operation for Automated Tape Layup](#), and [Ply Placing Operation for Automated Fiber Placement](#).

- **Average Curvature:** this is the ply's average Gaussian curvature. Total average curvature is the product of this geometric property and **Surface Area Filled**. Used to determine [Ply Deformation Level](#).
- **Max Curvature:** this is the ply's maximum Gaussian curvature. Total maximum curvature is the product of this geometric property and **Surface Area Filled**. Used to determine [Ply Deformation Level](#).
- **Curvature Deviation:** this is the standard deviation of the Gaussian curvature across the ply. Total curvature standard deviation is the product of this geometric property and the **Surface Area Filled**. Used to determine [Ply Deformation Level](#).
- **Direction:** this is the 0 direction of the rosette, specified as a unit vector. It specifies how the ply is oriented with respect to the part as a whole.
- **Orientation:** this is the angle between the 0 direction of the rosette and the ply's fiber direction (that is, the direction of the ply's warp tows).
- **Sequence:** determines the order in which the ply is laid up. This is set to -1 if the ply's ordering information is not available in CAD metadata.
- **Material Name:** specifies the material used by the ply, as extracted from the CAD model. The cost model uses this name to look up material properties in the material table for the current VPE. See [Materials for Composites](#).

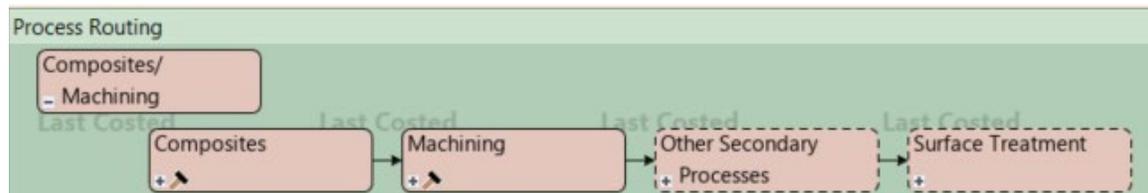
Core GCD

The cost model uses the following Core GCD properties:

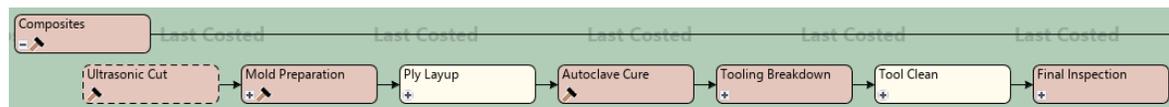
- **Material Name:** specifies the material used by the core, as extracted from the CAD file metadata. The cost model uses this name to look up material properties in the material table for the current VPE, for example, in order to determine the cost per unit area for a given core's material. See [Materials for Composites](#).
- **Perimeter:** perimeter of the core. This is the total length of the core edges that must be aligned with a template during core placement.
- **Sequence:** determines the layer in which the core is placed. This is set to -1 if the core's sequence information is not available in CAD metadata.
- **Surface Area:** surface area of the core, including all surfaces of the core.
- **Purchase price:** cost per unit area for the core.

Routing and Feasibility for Composites

Composites routings include processes from the Composites process group, as well as secondary machining processes (on a 5-axis mill), optional Ultrasonic Scanning (from the process group Other Secondary Processes), and optional Manual Paint (from the Surface Treatment process group):



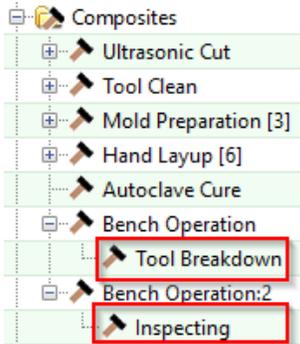
Composites processes include a layup process, preceded by ply-cutting and mold-preparation processes, and followed by curing, breakdown, and inspection processes:



In particular, Composites routings include the following:

- Ultrasonic Cut: models unrolling, cutting, and any necessary splicing of ply material. It also models indenting and unloading the plies. It is only included if the Ply Layup process is Hand Layup.
- Mold Preparation: models applying and curing some number of coats of mold release material, as well as applying and curing tack.
- Ply Layup: models the process of laying up plies onto a mold. This is either Hand Layup, Automated Fiber Placement, or Automated Tape Layup—see [Ply Layup](#).
- Autoclave Cure: models attaching and detaching thermocouples, loading and unloading the part, and curing the part with heat and pressure in an autoclave.
- Tooling Breakdown: models moving the part and tooling into a work cell, removing the vacuum bag and part, and moving the empty tooling out of the work cell.
- Tool Clean: models manual, laser, or cryogenic cleaning of the mold. See [Tool Clean](#).
- Final Inspection: models visually inspecting the finished part.

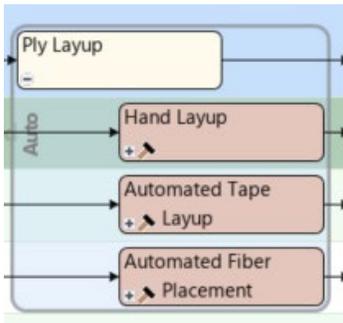
Tool Breakdown (which is under Tooling Breakdown) and Inspecting (which is under Final Inspection) are component-level operations of the Bench Operation process. Bench Operation occurs twice in Composites routings. Each occurrence has a single child operation, either Tool Breakdown or Inspecting:



See also [Secondary Processes](#).

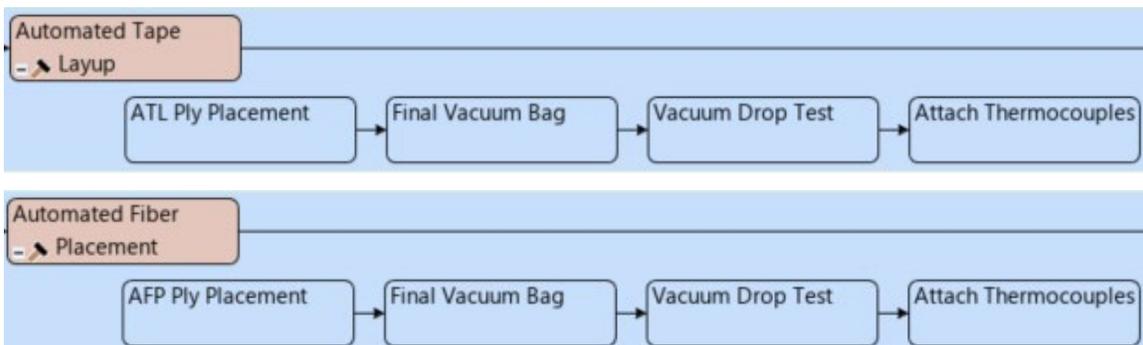
Ply Layup

Ply Layup is implemented by either Hand Layup, Automated Fiber Placement (AFP), or Automated Tape Layup (ATL):



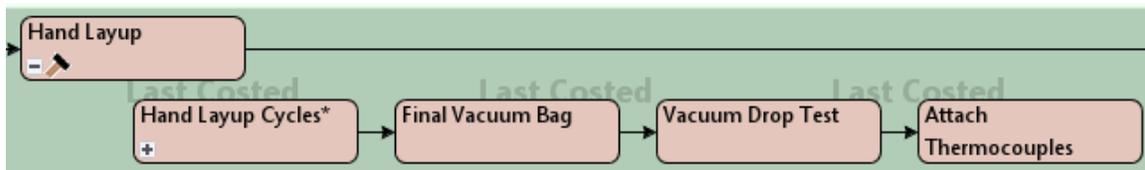
Hand Layup is included by default. Users can manually select ATL or AFP instead. ATL and AFP are feasible only if the part has no cores. Every layup process is feasible only if all the part's materials are compatible with the process (as indicated by the material properties **Can AFP**, **Can ATL**, and **Can HLU**).

ATL and AFP include the following:



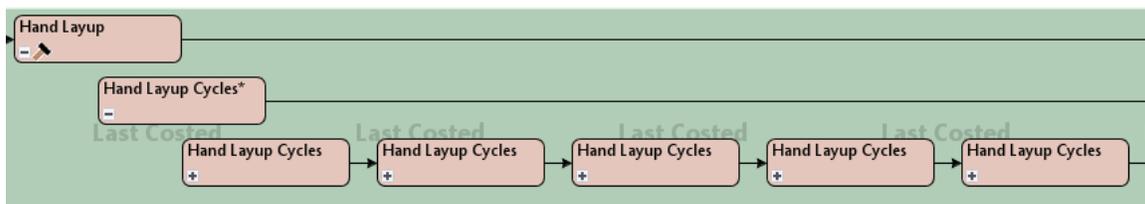
- ATL or AFP Ply Placement (component-level operation):
- Final Vacuum Bag (process)
- Vacuum Drop Test (component-level operation)
- Attach Thermocouples (component-level operation)

Hand Layup includes the following:

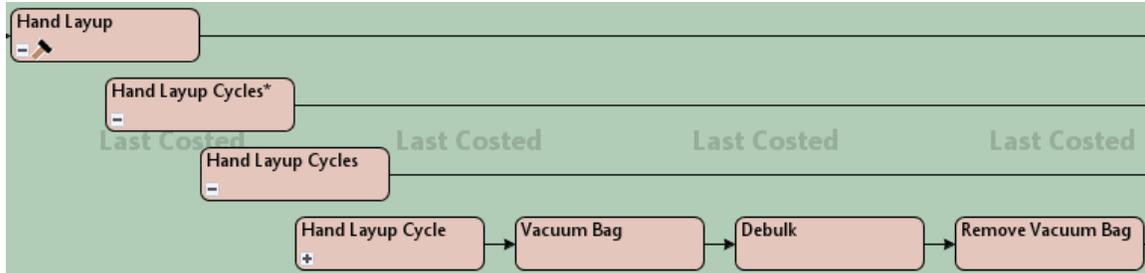


- Hand Layup Cycles
- Final Vacuum Bag
- Vacuum Drop Test
- Attach Thermocouples

There are multiple occurrences of Hand Layup Cycles:



Each occurrence consists of a Hand Layup Cycle (laying up one or more ply or core layers), followed by debulking (using a vacuum bag):

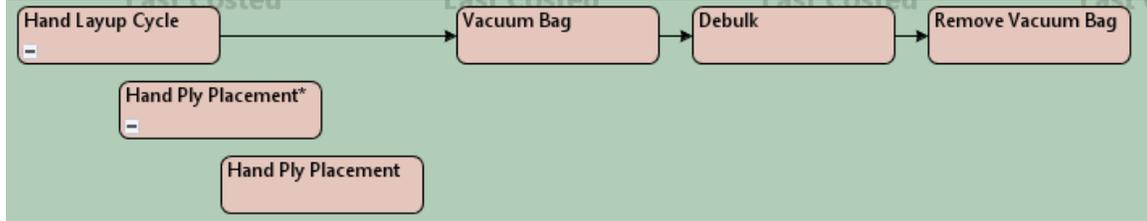


- Hand Layup Cycle (laying up one or more ply or core layers)
- Vacuum Bag
- Debulk
- Remove Vacuum Bag

Each Hand Layup Cycle consists of the following sequence:

- One ply or core *placement cycle*
- Vacuum Bag process
- Debulk component-level operation
- Remove Vacuum Bag component-level operation

Each placement cycle is either a ply placement cycle or a core placement cycle. The first placement cycle is a ply placement cycle; one of the subsequent cycles is a core placement cycle, and the rest are ply placement cycles.



Each ply placement cycle consists of one or more Ply Placing operations.

Each core placement cycle consists of the following sequence of core operations:

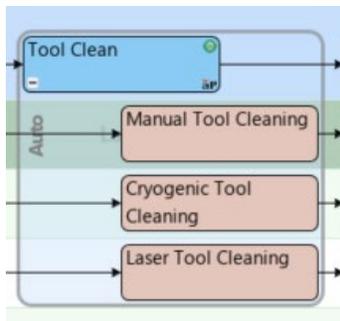
- Core Potting
- Core Splicing
- Core Placing

By default in starting point VPEs, the first placement cycle (before the first Debulk) consists of a single occurrence of the Ply Placing operation. Administrators can customize this default with the cost model variable **defaultNumPliesBeforeFirstDebulk** (1 in starting point VPEs). Users can override the default on a per-part basis with the setup option **Number of Ply Sequences Before First Debulk**.

Subsequent ply placement cycles each consist of 3 occurrences of the Ply Placing operation, by default in starting point VPEs. Administrators can customize this default with the cost model variable **defaultNumPliesPerDebulkCycle** (3 in starting point VPEs). Users can override the default on a per-part basis with the setup option **Number of Ply Sequences Per Debulk Cycle**.

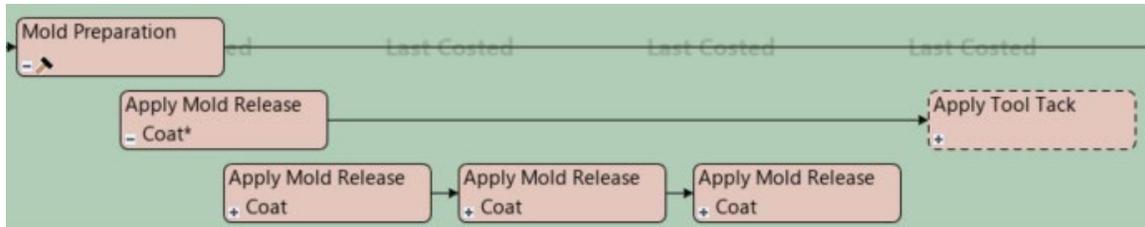
Tool Clean

Tool Clean: three alternative, component-level operations are available for tool cleaning:

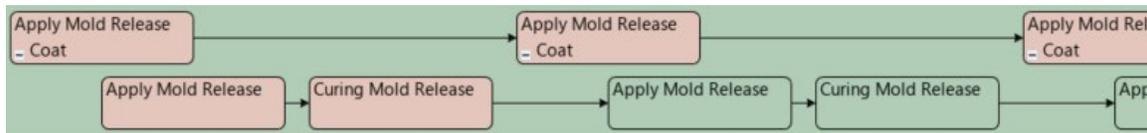


- Manual Tool Cleaning: tool cleaned by hand using an acetone solvent. This is auto-included.
- Cryogenic Tool Cleaning: tool blasted clean with a cryogenic cleaning device. Can be included manually.
- Laser Tool Cleaning: tool cleaned using a hand-held laser cleaning device. Can be included manually.

Mold Preparation: mold preparation consists of the application of some number of coats of mold release (three coats, by default in starting point VPEs), optionally followed by the application of tool tack (included, by default; can be manually excluded).



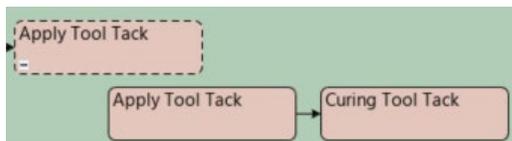
For each mold release coat, two component-level operations are performed:



- Applying Mold Release
- Curing Mold Release

Administrators can customize the default number of coats with the cost model variable **defaultNumMoldReleaseCoats** (3 in starting point VPEs). Users can override the default with the setup option **Number of Mold Release Agent Coats**.

Application of tool tack consists of the following component-level operations:



- Applying Tool Tack
- Curing Tool Tack

Tool tack application is included by default but can be manually excluded.

Secondary Processes

Secondary processes include the following:

- 5-axis Mill: profile milling and hole making, provided by the Machining process group.
- Ultrasonic Scanning: C-Scan or A-Scan, provided by Other Secondary Processes. C-Scan is auto-included. Users can manually include A-scan instead, or manually exclude ultrasonic scanning altogether.
- Manual Paint: provided by the Surface Treatment process group, auto included. Users can manually exclude it.

Machine Selection for Composites

Machine selection is covered in the following sections:

- Ultrasonic Cut Machine Selection
- Machine Selection for Mold Preparation, Hand Layup, and Bench Operation
- Tool Clean Machine Selection
- Automated Fiber Placement Machine Selection
- Automated Tape Layup Machine Selection
- Autoclave Cure Machine Selection

Ultrasonic Cut Machine Selection

aPriori selects the feasible machine that results in the lowest estimated per-part overhead cost. A machine is feasible only if the following holds:

- Machine property **Table Width** is sufficiently greater than the raw-material width for all the ply materials used by the part. Table width must exceed raw-material width by at least the value of the cost model variable **materialRollWidthAllowance** (100mm in starting point VPEs). Each ply's material name is specified by the geometric property **Material Name**. Each material's width is specified by the material property **Material Width**.

Per-part overhead cost is estimated with the following formulas:

Estimated Overhead Cost = Total Overhead Rate * (Cut Time + Setup Time)

Estimated overhead cost depends on the following:

- Total overhead rate: this is the sum of the machine properties **Direct Overhead Rate** and **Indirect Overhead Rate**.
- Cut time: this is estimated based on the machine property **Cut Rate** and on the sum of the perimeters of all the part's non-laminate plies. Each ply's perimeter, which includes cutout perimeters, is specified by the geometric property **Perimeter**.
- Setup time: This is estimated as the time to unroll table-length sections of raw material as many times as required for cutting all the part's plies (see formula).

**Setup Time =
(Machine Table Length / Unroll Raw Material Rate) *
Number of Required Table-length Sections**

Setup time depends on the following:

- Machine table length: specified by the machine property **Table Length**.
- Unroll raw material rate: specified by the cost model variable **unrollRawMaterialRate** (1400mm/sec in starting point VPEs).
- Number of required table-length sections (see formula). This is the sum of the number of sections required by each material type. See the formula below.

Number of Required Table-length Sections for a Given Material Type = roundup(Total Area of Plies / Material Utilization) / Machine Table Area

For a given material type, the number of required table-length sections of raw material depends on the following:

- Total area of plies: this is the sum of the **surfaceAreas** of the plies of the given material type.
- Material utilization: this is the value of the material property **Material Utilization** for the given material type
- Machine table area: this is the product of the machine properties **Table Length** and **Table Width**.

aPiori selects only from preferred machines, if there is a feasible preferred machine and the cost model variable **usePreferredMachines** is set to **true** (the default in starting point VPEs). If there is no feasible preferred machine, or if the cost model variable **usePreferredMachines** is set to **false**, aPiori selects from all machines. A machine is preferred if the machine property **isPreferred** (typically displayed as **Is Preferred**) is **true**.

Machine Selection for Mold Preparation, Hand Layup, and Bench Operation

The machines for Mold Preparation, Hand Layup, and Bench Operation represent work areas of various sizes. For these processes, aPiori selects the lowest-overhead machine that can accommodate the length and width of the mold for the part: the mold length and width (see **Tool Length, Width, and Area**) must be no greater than the machine properties **Usable Length** and **Usable Width**.

Overhead, here, is the sum of the machine properties **Direct Overhead Rate** and **Indirect Overhead Rate**.

aPiori selects only from preferred machines, if there is a feasible preferred machine and the cost model variable **usePreferredMachines** is set to **true** (the default in starting point VPEs). If there is no feasible preferred machine, or if the cost model variable **usePreferredMachines** is set to **false**, aPiori selects from all machines. A machine is preferred if the machine property **isPreferred** (typically displayed as **Is Preferred**) is **true**.

Tool Clean Machine Selection

Machines for the Tool Clean process represent a work area (for manual cleaning) or a combination of a work area and a laser or cryogenic cleaning device. Manual tool cleaning is included in the routing by default, but the user can override the default, and include cryogenic or laser cleaning instead (see **Tool Clean**).

For this process, aPiori selects the lowest-overhead, feasible machine. Overhead, here, is the sum of the machine properties **Direct Overhead Rate** and **Indirect Overhead Rate**.

A machine is considered feasible if both the following hold:

- Machine can accommodate the length and width of the mold for the part: the mold length and width (see [Tool Length, Width, and Area](#)) must be no greater than the machine properties **Usable Length** and **Usable Width**.
- The machine property **Cleaning Method** is set to the appropriate value for the current routing:
 - **manual**, if Manual Tool Cleaning is in the routing.
 - **cryogenic**, if Cryogenic Tool Cleaning is in the routing.
 - **laser**, if Laser Tool Cleaning is in the routing.

aPriori selects only from preferred machines, if there is a feasible preferred machine and the cost model variable **usePreferredMachines** is set to **true** (the default in starting point VPEs). If there is no feasible preferred machine, or if the cost model variable **usePreferredMachines** is set to **false**, aPriori selects from all machines. A machine is preferred if the machine property **isPreferred** (typically displayed as **Is Preferred**) is **true**.

Automated Fiber Placement Machine Selection

For Automated Tape Layup, aPriori selects the lowest-overhead, feasible machine. Overhead, here, is the sum of the machine properties **Direct Overhead Rate** and **Indirect Overhead Rate**.

A machine is considered feasible if all the following hold:

- Machine can accommodate the part's height; that is, part height is no greater than the machine property **Max Vertical Travel Distance**.
- Machine can accommodate the part's length; that is, part length is no greater than the machine property **Table Length**.
- Machine can accommodate the part's width; that is, part width is no greater than the machine property **Table Width**.
- Machine spool can accommodate the width of the roll of raw material for each of the part's materials; that is, the **Material Width** of part's widest material is no greater than the machine's **Max Material Width**.
- Machine can accommodate the number of active spools; that is, **Number of Active Spools** is no greater than the machine property **Total Number of Spools**.
- Machine can accommodate the collective width of all the active spools with the part's widest material; that is, the machine's **Max Bandwidth** is greater than the product of **Number of Active Spools** and **Material Width** for the part's widest material.

aPriori selects only from preferred machines, if there is a feasible preferred machine and the cost model variable **usePreferredMachines** is set to **true** (the default in starting point VPEs). If there is no feasible preferred machine, or if the cost model variable **usePreferredMachines** is set to **false**, aPriori selects from all machines. A machine is preferred if the machine property **isPreferred** (typically displayed as **Is Preferred**) is **true**.

Automated Tape Layup Machine Selection

For Automated Tape Layup, aPriori selects the lowest-overhead, feasible machine. Overhead, here, is the sum of the machine properties **Direct Overhead Rate** and **Indirect Overhead Rate**.

A machine is considered feasible if all the following hold:

- Machine can accommodate the part's height; that is, part height is no greater than the machine property **Max Vertical Travel Distance**.
- Machine can accommodate the part's length; that is, part length is no greater than the machine property **Table Length**.
- Machine can accommodate the part's width; that is, part width is no greater than the machine property **Table Width**.
- Machine can accommodate the width of the roll of raw material for each of the part's materials; that is, the **Material Width** of part's widest material is no greater than the machine's **Max Material Width**.

aPriori selects only from preferred machines, if there is a feasible preferred machine and the cost model variable **usePreferredMachines** is set to **true** (the default in starting point VPEs). If there is no feasible preferred machine, or if the cost model variable **usePreferredMachines** is set to **false**, aPriori selects from all machines. A machine is preferred if the machine property **isPreferred** (typically displayed as **Is Preferred**) is **true**.

Autoclave Cure Machine Selection

For Autoclave Cure, aPriori selects the lowest-overhead, feasible machine. Overhead, here, is the sum of the machine properties **Direct Overhead Rate** and **Indirect Overhead Rate**.

A machine is considered feasible if both the following hold:

- Machine's length can accommodate the length of the mold for the part. That is, the mold length (see [Tool Length, Width, and Area](#)) must be no greater than 80% of the machine's **Usable Length**, in starting point VPEs. Administrators can customize this percentage with the cost model variable **autoclaveSizeCapacitySafetyFactor** (0.8 in starting point VPEs).
- Machine's diameter can accommodate the diagonal of the mold for the part. That is, the mold diagonal must be no greater than the machine's **Usable Diameter**. The mold diagonal is $((\text{Tool Length}^2) + (\text{Tool Width}^2))^{0.5}$. See [Tool Length, Width, and Area](#).

aPriori selects only from preferred machines, if there is a feasible preferred machine and the cost model variable **usePreferredMachines** is set to **true** (the default in starting point VPEs). If there is no feasible preferred machine, or if the cost model variable **usePreferredMachines** is set to **false**, aPriori selects from all machines. A machine is preferred if the machine property **isPreferred** (typically displayed as **Is Preferred**) is **true**.

Cost Algorithms and Calculations for Composites

This section covers the following topics:

- Labor-dependent and Labor-independent Tasks
- Yields for Composites
- Ultrasonic cutting:
 - Ultrasonic Cut Process
 - Ultrasonic Cutting Operation
- Tool cleaning:
 - Tool Clean Process
 - Manual Tool Cleaning Operation
 - Cryogenic Tool Cleaning Operation
 - Laser Tool Cleaning Operation
- Mold preparation:
 - Mold Preparation Process
 - Applying Mold Release Operation
 - Curing Mold Release Operation
 - Applying Tool Tack Operation
 - Curing Tool Tack Operation
- Hand layup:
 - Hand Layup Process
 - Ply Placing Operation for Hand Layup
 - Core Potting Operation for Hand Layup
 - Core Splicing Operation for Hand Layup
 - Core Placing Operation for Hand Layup
 - Debulk Component-level Operation
 - Vacuum Bag Process
 - Remove Vacuum Bag Component-level Operation
- Automated tape layup:
 - Automated Tape Layup Process
 - Ply Placing Operation for Automated Tape Layup
- Automated fiber placement:
 - Automated Fiber Placement Process
 - Ply Placing Operation for Automated Fiber Placement
- Other layup-related sections:
 - Final Vacuum Bag Process

- Vacuum Bag Drop Test Component-level Operation
- Attach Thermocouples Component-level Operation
- Ply Deformation Level
- Autoclave Cure Process
- Bench operations:
 - Bench Operation Process
 - Inspecting Component-level Operation
 - Tool Breakdown Component-level Operation
- Tool Length, Width, and Area
- Overhead Calculations for Composites

Labor-dependent and Labor-independent Tasks

A *labor-dependent task* is one that can be sped up by using additional operators. In particular, a labor-dependent task is one whose elapsed duration is inversely proportional to the number of operators performing it. *Labor-dependent process time* for a process is the total time it would take 1 operator to perform the labor-dependent tasks that the process models.

A *labor-independent task* is one that is not labor-dependent. *Labor-independent process time* for a given process is the total elapsed duration of the labor-independent tasks that the process models.

Yields for Composites

These formulas apply to all Composites processes.

Final Yield = Final Output Volume / Local Input Volume

Final yield affects material, labor, and overhead costs per part. It is the fraction of parts created by this process in the current production scenario that will survive as good parts once any secondary processes are completed. That is, final yield is the fraction of parts created by this process that are *not* discarded as scrap parts, either by this process or by a downstream process. Final yield depends on the following:

- Final output volume is the number of parts created by this process that are *not* discarded as scrap parts, either by this process or by a downstream process. It is the product of the annual volume and number of production years, specified in the Production Scenario screen of the Cost Guide.
- Local Input volume (see the formula below). This is the total number of parts produced by this process, including all parts discarded as scrap from this process or downstream processes.

Local Input Volume = Local Output Volume + Number of Scrap Parts for This Process

Local input volume is the total number of parts produced by this process in the current scenario, including all parts discarded as scrap from this process or downstream processes. It is the sum of the following:

- Local output volume (see the formula below). This is the number of parts produced by this process, excluding parts discarded as scrap by this process, but including parts that are discarded as scrap by downstream processes.
- Number of scrap parts for this process (see the formula below)

Local Output Volume = Final Output Volume + Number of Scrap Parts Downstream

Local output volume is the number of parts produced by this process in the current scenario, excluding parts discarded as scrap by this process, but including parts that are discarded as scrap by downstream processes. It is the sum of the following:

- Final output volume is the number of parts created by this process that are *not* discarded as scrap parts, either by this process or by a downstream process. It is the product of the annual volume and number of production years, specified in the Production Scenario screen of the Cost Guide
- Number of Scrap Parts Downstream. This the number of parts discarded as scrap by downstream processes.

**Number of Scrap Parts for This Process =
(Local Output Volume / Local Good Part Yield) – Local Output Volume**

Number of scrap parts for this process is the number of parts produced by this process in the current scenario that are discarded as scrap by this process, before any downstream process is performed on them. It is a function of the following:

- Local output volume (see the formula above). This is the number of parts produced by this process, excluding parts discarded as scrap by this process, but including parts that are discarded as scrap by downstream processes.
- Local good part yield (specified by the machine property **Good Part Yield**). This is the fraction of parts produced by this process that are not discarded as scrap by this process but may be discarded as scrap by downstream processes.

Ultrasonic Cut Process

**Labor Time =
Labor Dependent Process Time * Labor Time Standard**

Labor time is the product of the following:

- Labor-dependent process time: this is the sum of the values of the formula **Labor Dependent Process Time** (the cutting times) for all the child operations. See [Ultrasonic Cutting Operation](#).
- Labor time standard: specified as the machine property **Labor Time Standard**. This multiplier is used to account for otherwise unaccounted for factors that affect labor time, such as operator fatigue or time spent by the operator for cleaning or maintenance.

**Cycle Time =
(Labor Independent Process Time +
(Labor Dependent Process Time / Number of Operators)) *
Cycle Time Adjustment Factor**

Cycle time depends on the following:

- Labor-dependent process time: this is the sum of the values of the formula **Labor Dependent Process Time** (identifying and unloading times) for all the child operations. See [Ultrasonic Cutting Operation](#).
- Labor-independent process time: this is the sum of the values of the formula **Labor Independent Process Time** (the cutting times) for all the child operations. See [Ultrasonic Cutting Operation](#).
- Number of operators: by default, this is specified by the machine property **Number of Operators**. Users can override the default on a per-part basis with the setup option **Number of Operators**.

**Batch Setup Cost per Part =
(Setup Time per Part * (Labor Rate + Direct Overhead Rate))**

This includes costs for moving rolls of raw material from cold storage, loading rolls onto the machine, and unrolling machine-table-length sections as many times as required for cutting all the part's plies. Batch setup cost per part depends on the following:

- Setup time per part (see formula)
- Labor rate (specified by the machine property **Labor Rate**)
- Direct overhead rate (see [Direct and Indirect Overhead](#))

Setup Time Per Part = Raw Material Handling Time + Unroll Raw Material Time

Setup time per part is the sum of the following:

- Raw material handling time: this is the time to move each required roll of raw material from Cold Storage to room-temperature soak, plus the time to load each roll onto the machine once the soak is complete. The soak time is assumed to incur no overhead. The number of required rolls is assumed to be the number of different material types used by the part's plies. The handling time for a given material type is specified by the material property **Raw Material Handling Time**.
- Unroll raw material time (see formula)

**Unroll Raw Material Time =
(Machine Table Length / Unroll Raw Material Rate) *
Number of Required Table-length Sections**

This is the time to unroll table-length sections of raw material as many times as required for cutting all the part's plies. It depends on the following:

- Machine table length: specified by the machine property **Table Length**.
- Unroll raw material rate: specified by the cost model variable **unrollRawMaterialRate** (1400mm/sec in starting point VPEs).
- Number of required table-length sections (see formula). This is the sum of the number of sections required by each material type. See the formula below.

**Number of Required Table-length Sections for a Given Material Type =
roundup(Total Area of Plies / Material Utilization) / Machine Table Area**

For a given material type, the number of required table-length sections of raw material depends on the following:

- Total area of plies: this is the sum of the **surfaceAreas** of the plies of the given material type.
- Material utilization: this is the value of the material property **Material Utilization** for the given material type
- Machine table area: this is the product of the machine properties **Table Length** and **Table Width**.

Ultrasonic Cutting Operation

Cycle Time =

**Labor Independent Process Time +
(Labor Dependent Process Time / Number of Operators)**

Cycle time depends on the following:

- Labor-independent process time: this is cutting time—see the formula below.
- Labor-dependent process time (see formula)
- Number of operators: by default, this is specified by the machine property **Number of Operators**. Users can override the default on a per-part basis with the setup option [Number of Operators](#).

Labor Dependent Process Time = Identing Time + Unloading Time

Labor-dependent process time is the sum of the following:

- Identing time: during Ultrasonic Cutting, an ident is applied to the ply (typically an adhesive label). The time required is specified by the cost model variable **plyIdentTime** (8 seconds in starting point VPEs).
- Unloading time: the time to unload a ply from the cutting machine is specified by one of the following cost model variables, depending on the ply's surface area:
 - **plyUnloadTimeSmall** (3 seconds in starting point VPEs): used if the geometric property **plySurfaceAreaFilled** is less than the cost model variable **plySmallLimitArea** (800,000 square millimeters in starting point VPEs).
 - **plyUnloadTimeMedium** (9 seconds in starting point VPEs): used if **plySurfaceAreaFilled** is less than the cost model variable **plyMediumLimitArea** (8,000,000 square millimeters in starting point VPEs).
 - **plyUnloadTimeLarge** (30 seconds in starting point VPEs): **plySurfaceAreaFilled** is greater than or equal to **plyMediumLimitArea** (8,000,000 square millimeters in starting point VPEs).

Labor Independent Process Time =

(Total Cut Length / Cut Rate) / Raw Material Stack Count

This is the cutting time for the operation. This value is converted from minutes to seconds. Cutting time in minutes is determined according to this formula by using the following values:

- Total cut length (see formula)

- Cut rate: by default in starting point VPEs, this is specified by the machine property **Cut Rate**. If the number of plies in a stack is greater than 1 (see [Raw Material Stack Count](#)), the machine rate is decreased by the factor specified by the cost model variable **cuttingDerateFactor** (0.8 in starting point VPEs). Users can override the calculated cut rate with the setup option [Cut Rate Override](#).
- Raw material stack count: This is the number of plies that are assumed to be cut at the same time. By default in starting point VPEs, plies are assumed to be cut one at a time. A cost model variable and setup option can be used to specify that multiple plies are stacked and all cut at the same time. See [Raw Material Stack Count](#).

Total Cut Length = Ply Perimeter Length + Total Splice Cut Length

Total cut length is the sum of the following:

- Ply perimeter length: this is the ply perimeter including the perimeters of interior contours. It is specified by the geometric property **Perimeter**.
- Tool splice cut length (see formula)

Total Splice Cut Length = Splice Cut Length * Total Number of Splice Cuts

Total splice cut length is the product of the following:

- Splice cut length: if the value of the geometric property **Orientation** is 0 for the ply, the cut length is assumed to be the ply **Length**. Otherwise, it is calculated with the formula below.
- Total number of splice cuts: for each splice, that is, for each pair of tow packets that are spliced together, there are two splice cuts. The number of pairs of tow packets that must be spliced together is given by $\text{roundup}(\text{plyWidth}/\text{materialWidth}) - 1$. This is 0 if ply width is not greater than raw material width.

$$\text{Splice Cut Length} = \frac{(((\text{Ply Length}^2) + (\text{Ply Width}^2))^{0.5} / \text{Total Number of Splice Cuts}) * \sin(\text{Ply Orientation})}$$

If the value of the geometric property **Orientation** is 0 for the ply, the cut length is assumed to be the ply **Length**. Otherwise, it is calculated with formula above, which depends on the following:

- Ply length: specified by the geometric property **Length**.
- Ply width: specified by the geometric property **Width**.
- Total number of splice cuts: this is given by $2 * (\text{roundup}(\text{plyWidth}/\text{materialWidth}) - 1)$. This is 0 if ply width is no greater than raw material width.
- Ply orientation: specified by the geometric property **Orientation**.

Note that **Length** runs along the ply fiber direction, and **Width** runs perpendicular to it. See [GCD Extraction for Composites](#).

Mold Preparation Process

Labor Time = Labor Dependent Process Time * Labor Time Standard

Labor time is the product of the following:

- Labor-dependent process time: this is the sum, across all child operations, of the value of **Apply Mold Release Time** or **Apply Tool Tack Time**. See [Applying Mold Release Operation](#) and [Applying Tool Tack Operation](#).
- Labor time standard: specified as the machine property **Labor Time Standard**. This multiplier is used to account for otherwise unaccounted for factors that affect labor time, such as operator fatigue or time spent by the operator for cleaning or maintenance.

**Cycle Time =
(Labor Independent Process Time +
(Labor Dependent Process Time / Number of Operators)) *
Cycle Time Adjustment Factor**

Cycle time depends on the following:

- Labor-independent process time: this is the sum of the curing times for all child operations. See [Curing Mold Release Operation](#) and [Curing Tool Tack Operation](#).
- Labor-dependent process time: this is the sum, across all child operations, of the value of **Apply Mold Release Time** or **Apply Tool Tack Time**. See [Applying Mold Release Operation](#) and [Applying Tool Tack Operation](#).
- Number of operators: by default, this is specified by the machine property **Number of Operators**. Users can override the default on a per-part basis with the setup option [Number of Operators](#).
- Cycle time adjustment factor: specified by the cost model variable **cycleTimeAdjustmentFactor** (1 in starting point VPEs). VPE administrators can change the cost model variable to globally adjust cycle times for Composites.

Applying Mold Release Operation

Applying mold release is a labor-dependent task (see [Labor-dependent and Labor-independent Tasks](#)).

Cycle Time = Apply Mold Release Time / Number of Operators

Cycle time depends on the following:

- Apply mold release time: this is the time it takes one operator to apply one coat of mold release to the tool. See formula.
- Number of operators: by default, this is specified by the machine property **Number of Operators**. Users can override the default with the setup option [Number of Operators](#).

Apply Mold Release Time = Tool Surface Area / Apply Mold Release Rate

This is the time it takes one operator to apply one coat of mold release to the tool. It depends on the following:

- Tool surface area: this is estimated based on the part dimensions and a perimeter allowance. See [Tool Length, Width, and Area](#).
- Apply mold release rate: this the application rate for one operator in area per unit time. It is specified by the cost model variable `applyMoldReleaseRate` (26,000mm²/sec in starting point VPE).

Additional Direct Costs = Mold Release Cost Per Area * Tool Surface Area

This is the cost for the mold release material consumed in one coating of the tool. It is the product of the following:

- Mold release cost per area (see formula)
- Tool surface area: this is estimated based on the part dimensions and a perimeter allowance. See formula.

Mold Release Cost Per Area = Mold Release Cost Per Volume / Mold Release Coverage Rate Per Volume

Mold release cost per area depends on the following:

- Mold release cost per volume: this is the value of the **Cost Per Volume** field for the tool shop variable named by [Mold Release Agent](#).
- Mold release coverage rate per volume: this is the area of mold covered by a given volume of release agent, in area per unit volume. It is looked up by [Mold Release Agent](#) in the toolshop **Tool Materials** table.

Tool Materials		
Edit ▼		
Name	Cost Per Volume (USD / L)	Material Type Name
Generic PVA Release Agent	9.59	Default
Generic Semi-Permanent Release Agent	24.28	Default

Curing Mold Release Operation

Curing is a labor-independent activity and is assumed to carry no labor cost. The curing time is looked up by [Mold Release Agent](#) in the lookup table `tblAvailableMoldReleaseAgents`.

Applying Tool Tack Operation

Applying tool tack is a labor-dependent task (see [Labor-dependent and Labor-independent Tasks](#)).

Cycle Time = Apply Tool Tack Time / Number of Operators

Cycle time depends on the following:

- Apply tool tack time: this is the time it takes one operator to apply tool tack to the tool. See formula.
- Number of operators: by default this is specified by the machine property **Number of Operators**. Users can override the default with the setup option **Number of Operators**.

Apply Tool Tack Time = Tool Surface Area / Apply Tool Tack Rate

This is the time it takes one operator to apply tool tack to the tool. It depends on the following:

- Tool surface area: this is estimated based on the part dimensions and a perimeter allowance. See **Tool Length, Width, and Area**.
- Apply tool tack rate: this the application rate for one operator in area per unit time. It is specified by the cost model variable **applyToolTackRate** (24,000mm²/sec in starting point VPEs).

Additional Direct Costs = Tool Tack Cost Per Area * Tool Surface Area

This is the cost for the tool tack material consumed in one coating of the tool. It is the product of the following:

- Tool tack cost per area (see formula)
- Tool surface area: this is estimated based on the part dimensions and a perimeter allowance. See formula.

Tool Tack Cost Per Area = Tool Tack Cost Per Volume / Tool Tack Coverage Rate Per Volume

Tool tack cost per area depends on the following:

- Tool tack cost per volume: this is the value of the tool shop variable **Cost Per Volume Tool Tack**.
- Tool tack coverage rate per volume: this is the area of mold covered by a given volume of tool tack, in area per unit volume. It is specified by the cost model variable **toolTackCoverageRatePerVolume** (17,500mm²/liter in starting point VPEs).

Curing Tool Tack Operation

Curing is a labor-independent activity, assumed to carry no labor cost. The curing time is specified by the cost model variable **toolTackCureTime** (35 seconds in starting point VPEs).

Hand Layup Process

Labor Time = Labor Dependent Process Time * Labor Time Standard

Labor time depends on the following:

- Labor-dependent process time: this is the sum of the values of **Labor Dependent Process Time** for all child operations and processes--see the following sections:
 - Ply Placing Operation for Hand Layup
 - Core Potting Operation for Hand Layup
 - Core Splicing Operation for Hand Layup
 - Core Placing Operation for Hand Layup
 - Vacuum Bag Process
 - Remove Vacuum Bag Component-level Operation
 - Final Vacuum Bag Process
 - Attach Thermocouples Component-level Operation
- Labor time standard: specified as the machine property **Labor Time Standard**. This multiplier is used to account for otherwise unaccounted for factors that affect labor time, such as operator fatigue or time spent by the operator for cleaning or maintenance.

**Cycle Time =
(Labor Independent Process Time +
(Labor Dependent Process Time / Number of Operators)) *
Cycle Time Adjustment Factor**

Cycle time depends on the following:

- Labor-independent process time: sum of the vacuum drop test hold time and the debulk times for child operations. See [Vacuum Bag Drop Test Component-level Operation](#) and [Debulk Component-level Operation](#).
- Labor-dependent process time: this is the sum of the values of **Labor Dependent Process Time** for all child operations and processes. See the **Labor Time** formula, above.
- Number of operators: by default, this is specified by the machine property **Number of Operators**. Users can override the default on a per-part basis with the setup option [Number of Operators](#).
- Cycle time adjustment factor: specified by the cost model variable **cycleTimeAdjustmentFactor** (1 in starting point VPEs). VPE administrators can change the cost model variable to globally adjust cycle times for Composites.

Material Cost

This is the sum of the core and ply material costs for all child operations. See [Ply Placing Operation for Hand Layup](#) and [Core Placing Operation for Hand Layup](#).

Ply Placing Operation for Hand Layup

Ply placing with hand layup is a labor-dependent task (see [Labor-dependent and Labor-independent Tasks](#)).

$$\text{Labor Dependent Process Time} = (\text{Ply Area} / \text{Ply Complexity Layup Rate}) * \text{Layup Guide Multiplier}$$

Layup time depends on the following:

- Ply area: specified by the geometric property **Surface Area**. This is the area of one side of the ply, after cutouts have been removed.
- Ply complexity layup rate: this is the layup rate, adjusted for ply complexity. See formula.
- Layup guide multiplier: this is 1 if the current machine has a laser projection system. Otherwise, this is a factor greater than 1, reflecting the increased time required for layup using manual layup guides. The factor is specified by the cost model variable **manualLayupGuideMultiplier** (1.1 in starting point VPEs).

$$\text{Complexity Ply Layup Rate} = \text{Weighted Flexibility Rate} + \text{Weighted Cutout Rate} + \text{Weighted Deformation Rate}$$

This is the layup rate, adjusted for three ply characteristics that affect layup rate:

- Ply material flexibility: a ply made of less flexible materials requires a slower layup rate.
- Ply cutouts: a ply with lots of perimeter and/or interior cutouts requires a slower layup rate.
- Ply deformation: a highly deformed ply requires a slower layup rate.

The adjusted value is somewhere between the minimum and maximum rate for plies of similar area to the current ply's area. These maximum and minimum rates are calculated based on values looked up by **Surface Area Filled** in the lookup table **tblPlyHandLayupTimes**.

Ply Layup Area (mm ²)	Ply Layup Time Max (min)	Ply Layup Time Min (min)
1,000,000.00	15.00	5.00
6,000,000.00	40.00	20.00
18,000,000.00	60.00	45.00
999,999,999,999.00	3,333,333,333.33	2,499,999,999.99

Complexity ply layup rate is a weighted sum of three different layup rates, each of which takes into account just one of the above ply characteristics (the weights add up to 1).

That is, it is the sum of the following:

- Weighted flexibility rate (see formula)
- Weighted cutout rate (see formula)

- Weighted deformation rate (see formula)

You can generate a layup rate report by selecting **Reports > SpreadSheet Reports... > Composites Report**.

Weighted Flexibility Rate = Flexibility Weighting * Flexibility Rate

Weighted flexibility rate is the product of the following:

- Flexibility weighting: this reflects the relative importance of material flexibility to layup rate. It is a number between 0 and 1, specified by the cost model variable **weightingHLUMaterialFlexibility** (0.5 in starting point VPEs). Note that flexibility weighting, cutout weighting, and deformation weighting must sum to 1.
- Flexibility rate: this is the layup rate, taking into account material flexibility.

Material flexibility is specified by the material property **Deformation Average Angle** (which is the average of **Deformation Limit Angle** and **Deformation Warning Angle**).

Flexibility rate is somewhere between the minimum rate, **Min Rate**, and the maximum rate, **Max Rate**, for the ply's area. **Min Rate** and **Max Rate** are calculated based on values looked up by **Surface Area Filled** in the lookup table **tblPlyHandLayupTimes**.

If material flexibility is some fraction of the way from the easiest-to-handle flexibility to the hardest-to-handle flexibility (for available materials), then flexibility rate is that fraction of the way from **Max Rate** to **Min Rate**.

For example, if material flexibility is halfway between the easiest-to-handle flexibility and the hardest-to-handle flexibility, then flexibility rate is halfway between **Max Rate** and **Min Rate**.

Weighted Cutout Rate = Cutout Weighting * Cutout Rate

Weighted cutout rate is the product of the following:

- Cutout weighting: this reflects the relative importance of cutouts to layup rate. It is a number between 0 and 1, specified by the cost model variable **weightingHLUPlyCutout** (0.1 in starting point VPEs). Note that flexibility weighting, cutout weighting, and deformation weighting must sum to 1.
- Cutout rate: this is the layup rate, taking into account ply cutouts.

The extent of cutouts is quantified by the *cutout ratio*, which is a ratio of geometric properties:

$$\text{cutout ratio} = \text{Surface Area} / \text{Surface Area Filled}$$

Surface Area Filled is the ply's area plus the estimated area of interior and perimeter cutouts.

Cutout rate is somewhere between the minimum rate, **Min Rate**, and the maximum rate, **Max Rate**, for the ply's area. **Min Rate** and **Max Rate** are calculated based on values looked up by **Surface Area** in the lookup table **tblPlyHandLayupTimes**.

If the cutout ratio is some fraction of the way from the easiest-to-handle ratio (1) to the hardest-to-handle ratio (0), then cutout rate is that fraction of the way from **Max Rate** to **Min Rate**.

For example, if the cutout ratio is halfway between the easiest-to-handle ratio to the hardest-to-handle ratio, then cutout rate is halfway between **Max Rate** and **Min Rate**.

Weighted Deformation Rate = Deformation Weighting * Deformation Rate

Weighted deformation rate is the product of the following:

- Deformation weighting: this reflects the relative importance of deformation to layup rate. It is a number between 0 and 1, specified by the cost model variable **weightingHLUPlyDeformation** (0.4 in starting point VPEs). Note that flexibility weighting, cutout weighting, and deformation weighting must sum to 1.
- Deformation rate: this is the layup rate, taking into account ply deformation.

The degree of deformation is quantified by a level between 1 and 5 (the higher the level, the greater the deformation). The level is determined based on the geometric properties **Average Curvature**, **Curvature Deviation**, and **Max Curvature**, and is intended to reflect a number of aspects of deformation, including the following:

- Degree of curvature: large curvature is harder to handle than mild curvature.
- Uniformity of curvature: varying curvature is harder to handle than overall, uniform curvature.
- Localization of curvature: distributed curvature (with multiple local extrema) is harder to handle than localized curvature.

See [Ply Deformation Level](#) for more information.

Deformation rate is somewhere between the minimum rate, **Min Rate**, and the maximum rate, **Max Rate**, for the ply's area. **Min Rate** and **Max Rate** are calculated based on values looked up by **Surface Area** in the lookup table **tblPlyHandLayupTimes**.

If the deformation level is some fraction of the way from the easiest-to-handle level (1) to the hardest-to-handle level (5), then the deformation rate is that fraction of the way from **Max Rate** to **Min Rate**.

For example, if the deformation level is halfway between the easiest-to-handle level and the hardest-to-handle level, then the deformation rate is halfway between **Max Rate** and **Min Rate**.

Ply Material Cost = (Ply Area / (Material Utilization / 100)) * Material Cost Per Unit Area

Material cost for a ply depends on the following:

- Ply area: specified by the geometric property **Surface Area**. This is the area of one side of the ply.
- Material utilization: this is the percentage of ply material that is used in parts and is not wasted. It is specified by the material property **Material Utilization**.
- Material cost per unit area: unit cost of ply material, specified in square meters by the material property **Material Cost Per Area**. This is converted to cost per square millimeter for use in this formula.

Core Potting Operation for Hand Layup

Core potting is a labor-dependent task (see [Labor-dependent and Labor-independent Tasks](#)).

$$\text{Labor Dependent Process Time} = \frac{(\text{Number of Part's Potted Holes} * \text{Time to Pot One Hole})}{\text{Number of Part's Cores}}$$

Potting is required for core regions that contain fastener holes. Potting stiffens such core regions by injecting low-density material, which hardens during curing, and prevents crushing during fastening.

Since fastener holes are not typically modeled in CAD, the total number of the part's fastener holes is specified by the setup option [Number of Holes Potted in Honeycomb Core](#), which is set to 0 by default in starting point VPEs. The time to perform potting on the current core is estimated as the time required for potting for the whole part, amortized over the part's total number of cores.

Core potting time depends on the following:

- Number of part's potted holes: this is the number of fastener holes go through cores. By default in starting point VPEs, this is assumed to be 0. Administrators can customize the default with the cost model variable **defaultNumCorePottingRequired**. Users can override the default on a per-part basis with the setup option [Number of Holes Potted in Honeycomb Core](#).
- Time to pot one hole: specified by the cost model variable **coreHolePottingTime** (40 seconds in starting point VPEs)
- Number of part's cores: this is the total number of Core GCDs in the part.

$$\text{Potting Material Cost} = \frac{(\text{Potting Material Unit Cost} * \text{Total Potting Material Required})}{\text{Number of Part's Cores}}$$

Since fastener holes are not typically modeled in CAD, the cost per core of potting material is estimated as the cost of the potting material required for the whole part, amortized over the part's total number of cores.

Consumable material cost depends on the following:

- Potting material unit cost: specified by the tool shop variable **Cost Per Volume Potting Compound**, specified in cost per cubic centimeters. This value is converted to cost per cubic millimeter for use in this formula.
- Total potting material required: this is the total volume of potting material required for the whole part. See formula.
- Number of part's cores: this is the total number of Core GCDs in the part.

$$\text{Total Potting Material Required} = \text{Potted Volume per Hole} * \text{Number of Part's Potted Holes}$$

Total potting material required for the whole part is the product of the following:

- Potted volume per hole: the potted region is assumed to be cylindrical, with a diameter specified by the cost model variable **pottingDiameterAllowance** (80mm in starting point VPEs), and a height specified by the geometric property **Height**.
- Number of part's potted holes: this is the number of fastener holes that go through cores. By default in starting point VPEs, this is assumed to be 0. Administrators can customize the default with the cost model variable **defaultNumCorePottingRequired**. Users can override the default on a per-part basis with the setup option **Number of Holes Potted in Honeycomb Core**.

Core Splicing Operation for Hand Layup

Core splicing is a labor-dependent task (see [Labor-dependent and Labor-independent Tasks](#)).

**Labor Dependent Process Time =
Core Splice Length / Core Splice Rate / Number of Part's Cores**

This is the time required for any core splicing. Core splicing is required when a core must be formed by splicing together two or more other cores (which may not be individually modeled in CAD). Splicing uses foaming adhesive to form butt joints. The total length of these joints for the whole part is specified by the setup option [Total Length of Honeycomb Core Splicing](#), which is set to 0 by default in starting point VPEs. The time to perform splicing on the current core is estimated as the time required for splicing for the whole part, amortized over the part's total number of cores.

Core splicing time depends on the following:

- Core splice length: this is the total length of the butt joints formed by core splicing for the whole part. By default in starting point VPEs, this is assumed to be 0. Administrators can customize the default with the cost model variable **defaultCoreSpliceLength**. Users can override the default on a per-part basis with the setup option [Total Length of Honeycomb Core Splicing](#).
- Core splice rate: the rate at which foaming adhesive is applied during splicing, specified by the cost model variable **coreSpliceRate** (0.1 meters per second in starting point VPEs)
- Number of part's cores: this is the total number of Core GCDs in the part.

**Splicing Material Cost =
(Splicing Material Unit Cost * Total Splicing Material Required) /
Number of Part's Cores**

This is the cost per core for splicing material (foaming adhesive), which is estimated as the cost of the splicing material required for the whole part, amortized over the part's total number of cores.

Splicing material cost per core depends on the following:

- Splicing material unit cost: this is the cost per unit length of the splicing material, specified by the tool shop variable **Cost Per Length Foaming Adhesive Tape**.
- Total splicing material required: this is the length of splicing material required for the whole part. It is the same as the total length of the butt joints formed by core

splicing for the whole part. By default in starting point VPEs, this is assumed to be 0. Administrators can customize the default with the cost model variable **defaultCoreSpliceLength**. Users can override the default on a per-part basis with the setup option [Total Length of Honeycomb Core Splicing](#).

- Number of part's cores: this is the total number of Core GCDs in the part.

Core Placing Operation for Hand Layup

Core placing is a labor-dependent task (see [Labor-dependent and Labor-independent Tasks](#)).

Layup Time = Core Template Location + (Core Perimeter / Core Layup Rate)

The time to lay up the current core depends on the following:

- Core template location: this is the time to locate a core placement template on the layup tool. It is specified by the cost model variable **coreTemplateLocationTime** (120 seconds in starting point VPEs).
- Core perimeter: specified by the geometric property **Perimeter**.
- Core layup rate: this is the rate, in length per unit time, at which a portion of the boundary of the core can be aligned with the template. The cost model assumes that only the perimeter of the core requires alignment. The rate is specified by the cost model variable **coreLayupRate** (100 millimeters per second in starting point VPEs).

Core Material Cost

Material cost is taken from the GCD property **Purchase Price**, if available. Otherwise, material cost is given by the following formula:

Calculated Material Cost = (Core Surface Area / 2) * Core Cost per Area

Calculated material cost for a core depends on the following:

- Core surface area: specified by the geometric property **Surface Area**.
- Core cost per area: specified by the **Purchase Price** geometric property of the Core GCD. If the property is not populated, this is looked up by the core's **Material Name** in the Materials table. If the core's material name is not found, the cost model uses the name specified by the cost model variable **defaultCoreMaterial** (**Generic Core Material** in starting point VPEs).

Debulk Component-level Operation

Debulk time is specified by the cost model variable **debulkTime** (20 minutes in starting point VPEs). This is considered a labor-independent task and is assumed to carry no labor cost.

Vacuum Bag Process

There are multiple occurrences of this process in the routing for a Composites part. Note that some costs apply only to the first occurrence.

Also note that the process occurs as a sub-process of the Hand Layup process.

Cycle Time = Labor Dependent Process Time / Number of Operators

Cycle time depends on the following:

- Labor-dependent process time (see formula)
- Number of Operators: this is the number of operators for the Hand Layup process. By default, it is specified by the machine property **Number of Operators**. Users can override the default on a per-part basis with the setup option **Number of Operators**.

**Labor Dependent Process Time =
Unroll Vacuum Bag Material Time + Install Vacuum Port Time +
Tape Vacuum Bag Edges Time**

Labor-dependent process time is the sum of the following:

- Unroll vacuum bag material time: time to unroll the required amount of vacuum bag material prior to taping the bag edges to the mold. See formula.
- Install vacuum port time: this is 0 for all but the first occurrence of Vacuum Bag in the current routing. For the first occurrence, this is specified by the cost model variable **installVacuumPortTime** (300 seconds in starting point VPEs).
- Tape vacuum edges time (see formula)

**Unroll Vacuum Bag Material Time =
Tool Surface Length / Unroll Vacuum Bag Material Rate**

Unroll vacuum bag time depends on the following:

- Tool surface length (see **Tool Length, Width, and Area**)
- Unroll vacuum bag material rate: specified by the cost model variable **vacuumBagMaterialUnrollRate** (300mm/sec in starting point VPEs).

Tape Vacuum Edges Time = Part External Perimeter / Vacuum Bag Apply Rate

Tape vacuum edges time depends on the following:

- Part external perimeter: specified by the geometric property **External Perimeter**.
- Vacuum bag apply rate: specified by the cost model variable **applyVacuumBagRate** (30mm/sec in starting point VPEs).

Additional Direct Costs = Vacuum Bag Material Cost + Sealant Tape Material Cost

Additional direct costs are 0 for all occurrences of this process except the first one in the routing for the current part. Additional direct costs are the sum of the following:

- Vacuum bag material cost: this is 0 for all occurrences of this process except the first one. See formula.

- Sealant tape material cost: this is 0 for all occurrences of this process except the first one. See formula.

**Vacuum Bag Material Cost =
Vacuum Bag Cost per Area * Vacuum Bag Material Used**

Vacuum bag material cost is 0 for all occurrences of this process except the first one. It is the product of the following:

- Vacuum bag cost per area: specified in cost per square meter by the tool shop variable `costPerArea_vacuumBag`).
- Vacuum bag material used: this is 0 for all occurrences of this process except the first one. During the first occurrence, this is the area of vacuum bag used, which is assumed to be equal to the surface area of the tool—see [Tool Length, Width, and Area](#).

**Sealant Tape Material Cost =
Sealant Tape Material Cost Per Length * Sealant Tape Material Used**

Sealant tape material cost is 0 for all but the first occurrence of this process. It is the product of the following:

- Sealant tape material cost per length: specified by the tool shop variable `costPerLength_sealantTape`.
- Sealant tape material used: this is 0 for all but the first occurrence of this process. See formula.

**Sealant Tape Material Used =
Part External Perimeter * Sealant Tape Length Multiplier**

This is 0 for all but the first occurrence of this process. During the first occurrence, it is the product of the following:

- Part external perimeter: specified by the geometric property **External Perimeter** (the length of the part's contours, excluding internal contours such as internal cutouts).
- Sealant tape length multiplier: specified by the cost model variable `sealantTapeLengthMultiplier` (1 in starting point VPEs). Administrators can use the cost model variable to increase the amount of tape used relative to the part perimeter, if that better reflects your manufacturing practices.

Tool Length, Width, and Area

Tool length, width and area are calculated based on the part dimensions.

Tool area is given by the following:

$$\text{Tool Surface Area} = (\text{Part Length} + (2 * \text{Tool Perimeter Allowance})) * ((\text{Part Width} + (2 * \text{Tool Perimeter Allowance}))$$

Tool surface area depends on the following:

- Part length: the length of the part bounding box, specified by the geometric property **Length**.
- Part width: the width of the part bounding box, specified by the geometric property **Width**.
- Tool perimeter allowance: specified by the cost model variable **toolPerimeterAllowance** (150mm in starting point VPEs).

Tool length and width are given by the following:

Tool Length = (Part Length + (2 * Tool Perimeter Allowance))

Tool Width = ((Part Width + (2 * Tool Perimeter Allowance))

Tool length and width depend on the following:

- Part length: the length of the part bounding box, specified by the geometric property **Length**.
- Part width: the width of the part bounding box, specified by the geometric property **Width**.
- Tool perimeter allowance: specified by the cost model variable **toolPerimeterAllowance** (150mm in starting point VPEs).

Remove Vacuum Bag Component-level Operation

Cycle Time = Labor Dependent Process Time / Number of Operators

Cycle time depends on the following:

- Labor-dependent process time (see formula)
- Number of Operators: this is the number of operators for the Hand Layup process. By default, it is specified by the machine property **Number of Operators**. Users can override the default on a per-part basis with the setup option **Number of Operators**.

**Labor Dependent Process Time =
Part Exterior Perimeter / Vacuum Bag Removal Rate**

This is the time it takes one operator to remove the vacuum bag. This is assumed to be the total labor time required, regardless of the number of operators. It depends on the following:

- Part exterior perimeter: specified by the geometric property **External Perimeter** (the length of the part's contours, excluding internal contours such as internal cutouts).
- Vacuum bag removal rate: rate in distance per unit time at which the edge of the vacuum bag is removed from the edges of the part. It is specified by the cost model variable **vacuumBagRemovalRate** (300mm/sec in starting point VPEs).

Final Vacuum Bag Process

Cycle Time =

$$\frac{\text{Labor Dependent Process Time} * \text{Cycle Time Adjustment Factor}}{\text{Number of Operators}}$$

Cycle time depends on the following:

- Labor-dependent process time (see formula)
- Cycle time adjustment factor: specified by the cost model variable **cycleTimeAdjustmentFactor** (1 in starting point VPEs). VPE administrators can change the cost model variable to globally adjust cycle times for Composites.
- Number of Operators: this is the number of operators for the Hand Layup process. By default, it is specified by the machine property **Number of Operators**. Users can override the default on a per-part basis with the setup option **Number of Operators**.

Labor Dependent Process Time =

$$\begin{aligned} &\text{Unroll Vacuum Bag Material Time} + \\ &\text{Apply Release Film Time} + \\ &\text{Apply Release Peel Ply Time} + \\ &\text{Apply Breather Cloth Time} + \\ &\text{Install Vacuum Port Time} + \\ &\text{Tape Vacuum Bag Edges Time} \end{aligned}$$

Labor-dependent process time is the sum of the following:

- Unroll vacuum bag material time: time to unroll the required amount of vacuum bag material prior to taping the bag edges to the mold. See formula.
- Apply release film time: time apply release film, which helps retain resin on the laminate surface. See formula.
- Apply release peel ply time: time to apply a release barrier between the laminate surface and the breather cloth. See formula.
- Apply breather cloth time: time to apply breather cloth, which traps excess resin from the laminate. See formula.
- Install vacuum port time: this is the time to install the connector between the bag and the vacuum pump tubing. It is specified by the cost model variable **installVacuumPortTime** (300 seconds in starting point VPEs).
- Tape vacuum bag edges time: time to seal the bag to the mold. See formula.

Unroll Vacuum Bag Material Time =

$$\frac{\text{Tool Surface Length}}{\text{Unroll Vacuum Bag Material Rate}}$$

Unroll vacuum bag time depends on the following:

- Tool surface length (see **Tool Length, Width, and Area**)
- Unroll vacuum bag material rate: specified by the cost model variable **vacuumBagMaterialUnrollRate** (1400mm/sec in starting point VPEs).

**Apply Release Film Time =
Tool Surface Area / Release Film Apply Rate**

Time to apply release film depends on the following:

- Tool surface area (see Tool Length, Width, and Area)
- Release film apply rate: specified in area per unit time by the cost model variable **applyReleaseFilmRate** (7000mm²/sec in starting point VPEs).

**Apply Peel Ply Time =
Tool Surface Area / Release Peel Ply Apply Rate**

Time to apply a release barrier between the laminate surface and the breather cloth depends on the following:

- Tool surface area (see Tool Length, Width, and Area)
- Release peel ply apply rate: specified in area per unit time by the cost model variable **applyReleasePeelPlyRate** (7000mm²/sec in starting point VPEs).

**Apply Breather Cloth Time =
Tool Surface Area / Breather Cloth Apply Rate**

Time to apply the breather cloth depends on the following:

- Tool surface area (see Tool Length, Width, and Area)
- Breather cloth apply rate: specified in area per unit time by the cost model variable **applyBreatherClothRate** (7000mm²/sec in starting point VPEs).

Tape Vacuum Edges Time = Part External Perimeter / Vacuum Bag Apply Rate

Tape vacuum edges time depends on the following:

- Part external perimeter: this is the length of the part's contours, excluding internal contours. It is specified by the geometric property **External Perimeter**.
- Vacuum bag apply rate: specified by the cost model variable **applyVacuumBagRate** (30mm/sec in starting point VPEs).

**Additional Direct Costs =
Vacuum Bag Material Cost +
Release Film Material Cost +
Release Peel Ply Material Cost +
Breather Cloth Material Cost +
Sealant Tape Material Cost**

Additional direct costs for this process consist in costs for consumable materials. It depends on the following:

- Vacuum bag material cost (see formula)
- Release film material cost (see formula)
- Release peel ply material cost (see formula)
- Breather cloth material cost (see formula)
- Sealant tape material cost (see formula)

**Vacuum Bag Material Cost =
Vacuum Bag Cost per Area * Vacuum Bag Material Used**

Vacuum bag material cost is the product of the following:

- Vacuum bag cost per area: specified in cost per square meter by the tool shop variable `costPerArea_vacuumBag`.
- Vacuum bag material used: this is the area of vacuum bag used, which is assumed to be equal to the surface area of the tool—see [Tool Length, Width, and Area](#).

**Release Film Material Cost =
Release Film Material Cost per Area * Release Film Material Used**

Release film material cost is the product of the following:

- Release fill material cost per area: specified in cost per square meter by the tool shop variable `costPerArea_releaseFilm`.
- Release film material used: this is the area of release film used, which is assumed to be equal to the surface area of the tool—see [Tool Length, Width, and Area](#).

**Release Peel Ply Material Cost =
Release Peel Ply Material Cost per Area * Release Peel Ply Material Used**

Release peel ply material cost is the product of the following:

- Release peel ply material cost per area: specified in cost per square meter by the tool shop variable `costPerArea_releasePeelPly`.
- Release peel ply material used: this is the area of release film used, which is assumed to be equal to the surface area of the tool—see [Tool Length, Width, and Area](#).

**Breather Cloth Material Cost =
Breather Cloth Material Cost per Area * Breather Cloth Material Used**

Breather cloth material cost is the product of the following:

- Breather cloth material cost per area: specified in cost per square meter by the tool shop variable `costPerArea_breatherCloth`.
- Breather cloth material used: this is the area of release film used, which is assumed to be equal to the surface area of the tool—see [Tool Length, Width, and Area](#).

**Sealant Tape Material Cost =
Sealant Tape Material Cost Per Length * Sealant Tape Material Used**

Sealant tape material cost is the product of the following:

- Sealant tape material cost per length: specified by the tool shop variable `costPerLength_sealantTape`.
- Sealant tape material used: see formula.

**Sealant Tape Material Used =
Part External Perimeter * Sealant Tape Length Multiplier**

This is the product of the following:

- Part external perimeter: specified by the geometric property **External Perimeter** (the length of the part's contours, excluding internal contours such as internal cutouts).
- Sealant tape length multiplier: specified by the cost model variable **sealantTapeLengthMultiplier** (1 in starting point VPEs). Administrators can use the cost model variable to increase the amount of tape used relative to the part perimeter, if that better reflects your manufacturing practices.

Vacuum Bag Drop Test Component-level Operation

The cycle time for this operation is specified by the cost model variable **vacuumDropTestHoldTime** (20 minutes in starting point VPE). This is a labor-independent activity and is assumed to carry no labor cost.

Attach Thermocouples Component-level Operation

This operation occurs as part of the layup processes—see [Routing and Feasibility for Composites](#). It models attaching thermocouples to the part in preparation for the [Autoclave Cure Process](#).

Cycle Time = Labor Dependent Process Time / Number of Operators

Cycle time depends on the following:

- Labor-dependent process time (see formula)
- Number of operators: by default this is specified by the machine property **Number of Operators**. Users can override the default with the setup option **Number of Operators** for the current process—see [User Inputs for Composites](#).

**Labor Dependent Process Time =
Thermocouple Application Rate * Thermocouples Total Number Required**

Thermocouple connect time is the product of the following:

- Thermocouple application rate: this is the time required to attach a single thermocouple to the part. It is specified by the cost model variable **thermocoupleApplicationRate** (30 seconds in starting point VPEs).
- Thermocouples total num required: this is the total number of thermocouples required for the part. By default it is calculated based on tool surface area (see formula). Users can override the default with the setup option **Number of Thermocouples**.

**Thermocouples Total Num Required =
roundup(Upper Surface Area of Part / Thermocouple Application Density)**

Thermocouple total num required depends on the following (by default—see [Number of Thermocouples](#)):

- Upper surface area of part: half the part's **Surface Area**.
- Thermocouple application density: specified by the cost model variable **thermocoupleApplicationDensity** (465,000mm² in starting point VPEs). This is the maximum upper surface area of the part that can be covered by an individual thermocouple.

Automated Tape Layup Process

Labor Time =
(Labor Dependent Process Time * Labor Time Standard) +
Layup Time

Labor time depends on the following:

- Labor-dependent process time: this is the value of **Labor Dependent Process Time** for Attach Thermocouples—see [Attach Thermocouples Component-level Operation](#).
- Labor time standard: specified as the machine property **Labor Time Standard**. This multiplier is used to account for otherwise unaccounted for factors that affect labor time, such as operator fatigue or time spent by the operator for cleaning or maintenance.
- Layup time: this is the sum of the values of **Layup Time** for the child operations on the part's plies. One operator is assumed to oversee the layup operations. See [Ply Placing Operation for Automated Tape Layup](#).

Cycle Time =
(Labor Independent Process Time +
(Labor Dependent Process Time / Number of Operators)) *
Cycle Time Adjustment Factor

Cycle time depends on the following:

- Labor independent process time: this is the vacuum drop test hold time plus the sum of the layup times for all plies. See [Vacuum Bag Drop Test Component-level Operation](#) and [Ply Placing Operation for Automated Tape Layup](#).
- Labor dependent process time: this is the value of **Labor Dependent Process Time** for Attach Thermocouples—see [Attach Thermocouples Component-level Operation](#).
- Number of operators: by default, this is specified by the machine property **Number of Operators**. Users can override the default on a per-part basis with the setup option [Number of Operators](#).
- Cycle time adjustment factor: specified by the cost model variable **cycleTimeAdjustmentFactor** (1 in starting point VPEs). VPE administrators can change the cost model variable to globally adjust cycle times for Composites.

Programming Cost

By default, cost to program the layup machine is specified by the cost model variable **defaultATLProgrammingCost** (0 in starting point VPEs). Users can override the default on a per-part basis with the setup option [Automated Tape Layup Machine Programming Cost](#).

This value contributes to Capital Investment.

Ply Placing Operation for Automated Tape Layup

Ply placing for Automated Tape Layup (ATL) is a labor-independent task (see [Labor-dependent and Labor-independent Tasks](#)). The cost model assumes that a single operator oversees the automated operation. There is one occurrence of this operation for each ply of the current part.

$$\text{Layup Time} = \frac{\text{Ply Area}}{\text{Ply Complexity Layup Rate}} + (\text{Course Changes} * \text{Rapid Traverse Time})$$

Layup time depends on the following:

- Ply area: specified by the geometric property **Surface Area**. This is the area of one side of the ply.
- Ply complexity layup rate: this is the layup rate, adjusted for ply complexity. See formula.
- Course changes: this is the number of times the delivery head must break contact with the tool after finishing one course and position itself to start another course. It is the result of rounding down the ply width divided by the material width.
- Rapid traverse time: this is the average time required between finishing one course and starting the next. It is specified by the cost model variable **averageATLRapidTraverseTime** (5 seconds in starting point VPEs—this assumes unidirectional tape, requiring the delivery head to change direction and rapidly traverse the width of the ply between courses).

$$\text{Ply Complexity Layup Rate} = \text{Weighted Flexibility Rate} + \text{Weighted Cutout Rate} + \text{Weighted Deformation Rate} + \text{Weighted Aspect Rate}$$

This is the layup rate, adjusted for four ply characteristics that affect layup rate:

- Ply material flexibility: a ply made of less flexible materials requires a slower layup rate.
- Ply cutouts: a ply with lots of perimeter and/or interior cutouts requires a slower layup rate.
- Ply deformation: a highly deformed ply requires a slower layup rate.
- Ply aspect ratio: a ply with a smaller length-to-width aspect ratio requires a slower layup rate. (Note that length is the ply bounding box dimension that is

aligned with the ply direction. With a shorter course, the delivery head can't achieve as high a speed as with a longer course.)

The adjusted value is somewhere between the minimum and maximum rate. The maximum rate is specified by the machine property **Max Deposition Rate**. The minimum rate is assumed to be 1/6 the maximum rate, in starting point VPEs. Administrators can customize this fraction with the cost model variable **minLayupRateFactorATL** (0.16 in starting point VPEs).

Complexity ply layup rate is a weighted sum of four different layup rates, each of which takes into account just one of the above ply characteristics (the weights add up to 1). That is, it is the sum of the following:

- Weighted flexibility rate (see formula)
- Weighted cutout rate (see formula)
- Weighted deformation rate (see formula)
- Weighted aspect rate (see formula)

You can generate a layup rate report by selecting **Reports > SpreadSheet Reports... > Composites Report**.

Weighted Flexibility Rate = Flexibility Weighting * Flexibility Rate

Weighted flexibility rate is the product of the following:

- Flexibility weighting: this reflects the relative importance of material flexibility to layup rate. It is a number between 0 and 1, specified by the cost model variable **weightingATLMaterialFlexibility** (0.1 in starting point VPEs). Note that flexibility weighting, cutout weighting, deformation weighting, and aspect weighting must sum to 1.
- Flexibility rate: this is the layup rate, taking into account material flexibility.

Material flexibility is specified by the material property **Deformation Average Angle** (which is the average of **Deformation Limit Angle** and **Deformation Warning Angle**).

Flexibility rate is somewhere between the maximum rate (specified by the machine property **Max Deposition Rate**) and the minimum rate (1/6 the maximum rate, in starting point VPEs). If material flexibility is some fraction of the way from the easiest-to-handle flexibility to the hardest-to-handle flexibility (for available materials), then flexibility rate is that fraction of the way from the maximum rate to the minimum rate.

For example, if material flexibility is halfway between the easiest-to-handle flexibility and the hardest-to-handle flexibility, then flexibility rate is halfway between the maximum rate and the minimum rate.

Weighted Cutout Rate = Cutout Weighting * Cutout Rate

Weighted cutout rate is the product of the following:

- Cutout weighting: this reflects the relative importance of cutouts to layup rate. It is a number between 0 and 1, specified by the cost model variable **weightingATLPlyCutout** (0.4 in starting point VPEs). Note that flexibility weighting, cutout weighting, deformation weighting, and aspect weighting must sum to 1.

- Cutout rate: this is the layup rate, taking into account ply cutouts.

The extent of cutouts is quantified by the *cutout ratio*, which is a ratio of geometric properties:

$$\text{Cutout Ratio} = \text{Surface Area} / \text{Surface Area Filled}$$

Surface Area Filled is the ply's area plus the estimated area of interior and perimeter cutouts.

Cutout rate is somewhere between the maximum rate (specified by the machine property **Max Deposition Rate**) and the minimum rate (1/6 the maximum rate, in starting point VPEs). If cutout ratio is some fraction of the way from the easiest-to-handle ratio to the hardest-to-handle ratio, then cutout rate is that fraction of the way from the maximum rate to the minimum rate.

For example, if cutout ratio is halfway between the easiest-to-handle ratio and the hardest-to-handle ratio, then cutout rate is halfway between the maximum rate and the minimum rate.

Weighted Deformation Rate = Deformation Weighting * Deformation Rate

Weighted deformation rate is the product of the following:

- Deformation weighting: this reflects the relative importance of deformation to layup rate. It is a number between 0 and 1, specified by the cost model variable **weightingATLPlyDeformation** (0.3 in starting point VPEs). Note that flexibility weighting, cutout weighting, deformation weighting, and aspect weighting must sum to 1.
- Deformation rate: this is the layup rate, taking into account ply deformation.

The degree of deformation is quantified as a level between 1 and 5 (the higher the level, the greater the deformation). The level is determined based on the geometric properties **Average Curvature**, **Curvature Deviation**, and **Max Curvature**, and is intended to reflect a number of aspects of deformation, including the following:

- Degree of curvature: large curvature is harder to handle than mild curvature.
- Uniformity of curvature: varying curvature is harder to handle than overall, uniform curvature.
- Localization of curvature: distributed curvature (with multiple local extrema) is harder to handle than localized curvature.

See [Ply Deformation Level](#) for more information on how the cost model assigns a level to a ply.

Deformation rate is somewhere between the maximum rate (specified by the machine property **Max Deposition Rate**) and the minimum rate (1/6 the maximum rate, in starting point VPEs). If deformation level is some fraction of the way from the easiest-to-handle level (1) to the hardest-to-handle level (5), then deformation rate is that fraction of the way from the maximum rate to the minimum rate.

For example, if deformation level is halfway between the easiest-to-handle deformation and the hardest-to-handle deformation, then deformation rate is halfway between the maximum rate and the minimum rate.

Weighted Aspect Rate = Aspect Weighting * Aspect Rate

Weighted aspect rate is the product of the following:

- Aspect weighting: this reflects the relative importance of aspect ratio to layup rate. It is a number between 0 and 1, specified by the cost model variable **weightingATLAngleVsAspect** (0.2 in starting point VPEs). Note that flexibility weighting, cutout weighting, deformation weighting, and aspect weighting must sum to 1.
- Aspect rate: this is the layup rate, taking into account ply aspect ratio.
Aspect ratio, here, is ply **Length** divided by ply **Width**. Note that **Length** is the dimension of the ply bounding box that is aligned with the ply direction. The cost model defines three aspect-ratio levels:
 - Level 1 (fastest): aspect ratio $\geq 1 \frac{1}{3}$
 - Level 2 (intermediate): $\frac{3}{4} < \text{aspect ratio} < 1 \frac{1}{3}$
 - Level 3 (slowest): aspect ratio $\leq \frac{3}{4}$

Administrators can customize the level thresholds with the cost model variable **approxSquareRatio** (0.75 in starting point VPEs). The level thresholds are defined in terms of **approxSquareRatio** as follows:

- Level 1: aspect ratio $\geq 1 / \text{approxSquareRatio}$
- Level 2: $\text{approxSquareRatio} < \text{aspect ratio} < 1 / \text{approxSquareRatio}$
- Level 3: aspect ratio $\leq \text{approxSquareRatio}$

Aspect rate is somewhere between the maximum rate (specified by the machine property **Max Deposition Rate**) and the minimum rate (1/6 the maximum rate, in starting point VPEs). If aspect level is some fraction of the way from the fastest level (1) to the slowest level (3), then cutout rate is that fraction of the way from the maximum rate to the minimum rate.

For example, if aspect ratio level is halfway between the fastest level and the slowest level, then cutout rate is halfway between the maximum rate and the minimum rate.

Ply Material Cost =

$$\text{(Ply Area / (Material Utilization / 100)) * Material Cost Per Unit Area}$$

Material cost for a ply depends on the following:

- Ply area: specified by the geometric property **Surface Area**. This is the area of one side of the ply, before cutouts are removed.
- Material utilization: this is the percentage of ply material that is used in parts and is not wasted. It is specified by the material property **Material Utilization**.
- Material cost per unit area: unit cost of ply material, specified in square meters by the material property **Material Cost Per Area**. This is converted to cost per square millimeter for use in this formula.

Automated Fiber Placement Process

Labor Time =
(Labor Dependent Process Time * Labor Time Standard) +
Layup Time

Labor time depends on the following:

- Labor-dependent process time: this is the value of **Labor Dependent Process Time** for Attach Thermocouples—see [Attach Thermocouples Component-level Operation](#).
- Labor time standard: specified as the machine property **Labor Time Standard**. This multiplier is used to account for otherwise unaccounted for factors that affect labor time, such as operator fatigue or time spent by the operator for cleaning or maintenance.
- Layup time: this is the sum of the values of **Layup Time** for the child operations on the part's plies. One operator is assumed to oversee the layup operations. See [Ply Placing Operation for Automated Fiber Placement](#).

Cycle Time =
(Labor Independent Process Time +
(Labor Dependent Process Time / Number of Operators)) *
Cycle Time Adjustment Factor

Cycle time depends on the following:

- Labor independent process time: this is the vacuum drop test hold time plus the sum of the layup times for all plies. See [Vacuum Bag Drop Test Component-level Operation](#) and [Ply Placing Operation for Automated Fiber Placement](#).
- Labor dependent process time: this is the value of **Labor Dependent Process Time** for Attach Thermocouples—see [Attach Thermocouples Component-level Operation](#).
- Number of operators: by default, this is specified by the machine property **Number of Operators**. Users can override the default on a per-part basis with the setup option [Number of Operators](#).
- Cycle time adjustment factor: specified by the cost model variable **cycleTimeAdjustmentFactor** (1 in starting point VPEs). VPE administrators can change the cost model variable to globally adjust cycle times for Composites.

Programming Cost

By default, cost to program the layup machine is specified by the cost model variable **defaultATLProgrammingCost** (0 in starting point VPEs). Users can override the default on a per-part basis with the setup option [Automated Fiber Placement Machine Programming Cost](#) Automated Tape Layup Machine Programming Cost.

This value contributes to Capital Investment.

Ply Placing Operation for Automated Fiber Placement

Ply placing for Automated Fiber Placement (AFP) is a labor-independent task (see [Labor-dependent and Labor-independent Tasks](#)). The cost model assumes that a single operator oversees the automated operation. There is one occurrence of this operation for each ply of the current part.

$$\text{Layup Time} = \text{(Ply Area / Ply Complexity Layup Rate)} + \text{(Course Changes * Rapid Traverse Time)}$$

Layup time depends on the following:

- Ply area: specified by the geometric property **Surface Area**. This is the area of one side of the ply.
- Ply complexity layup rate: this is the layup rate (in area per unit time), adjusted for ply complexity. See formula.
- Course changes: this is the number of times the delivery head must break contact with the tool and position itself to start a new course. See formula.
- Rapid traverse time: this is the average time between finishing one course and starting the next. It is specified by the cost model variable **averageAFPRapidTraverseTime** (5 seconds in starting point VPEs—this assumes unidirectional material, requiring the delivery head to change direction and rapidly traverse the width of the ply between courses).

$$\text{Course Changes} = \text{roundup}(\text{Ply Width} / (\text{Spool Width} * \text{Number of Spools}))$$

This is the number of times the delivery head must break contact with the tool and position itself to start a new course. It depends on the following:

- Ply width: specified by the geometric property **Width**.
- Spool width: specified by the material property **Material Width**.
- Number of spools: this is the number of active spools. By default this is determined according to the formula below. Users can override the default with the setup option [Number of Active Spools](#).

$$\text{Number of Spools} = \text{min}(\text{Machine Total Number of Spools}, \text{rounddown}(\text{Machine Max Bandwidth} / \text{Max Material Width}))$$

By default, the number of active spools is the maximum number of spools that the machine can use, given all the following constraints:

- Number of spools is no greater than the total number of spools that the machine can accommodate.
- Total width of all spools is no greater than the machine's maximum bandwidth.
- Each spool's width is the material width for that ply (among all the part's plies) that has the largest material width.

So the default number of active spools depends on the following:

- Machine total number of spools: specified by the machine property **Total Number of Spools**. This is the maximum number of spools that can be active.
- Machine max bandwidth: this is the maximum total width of all active spools, specified by the machine property **Max Bandwidth**.
- Max material width: this is the material width of that ply (among all the part's plies) that has the largest value for the material property **Material Width**.

Users can override the default with the setup option [Number of Active Spools](#).

**Ply Complexity Layup Rate =
Linear Complexity Ply Layup Rate * Material Width * Number of Spools**

The complexity-adjusted area-based layup rate (in area per unit time) is the product of the following:

- Linear complexity ply layup rate: the complexity-adjusted linear ply layup rate (in distance per unit time). See formula.
- Material width: width of one spool. This is specified by the material property **Material Width**, for the current ply's material.
- Number of spools: this is the number of active spools. By default this is determined according to the formula above. Users can override the default with the setup option [Number of Active Spools](#).

**Linear Complexity Ply Layup Rate =
Weighted Flexibility Rate +
Weighted Cutout Rate +
Weighted Deformation Rate +
Weighted Aspect Rate +**

This is the complexity-adjusted, linear layup rate in distance per unit time, adjusted for four ply characteristics that affect layup rate:

- Ply material flexibility: a ply made of less flexible materials requires a slower layup rate.
- Ply cutouts: a ply with lots of perimeter and/or interior cutouts requires a slower layup rate.
- Ply deformation: a highly deformed ply requires a slower layup rate.
- Ply aspect ratio: a ply with a smaller length-to-width aspect ratio requires a slower layup rate. (Note that length is the ply bounding box dimension that is aligned with the ply direction, the direction along which each course is laid. With a shorter course, the delivery head can't achieve as high a speed as with a longer course.)

The adjusted value, linear complexity ply layup rate, is somewhere between the *minimum* and *maximum* rates, where the maximum rate (distance per unit time) is specified by the machine property **Max Deposition Rate**, and the minimum rate is assumed to be 1/6 the maximum rate, in starting point VPEs. Administrators can customize this fraction with the cost model variable **minLayupRateFactorAFP** (0.16 in starting point VPEs).

Linear complexity ply layup rate is a weighted sum of four different layup rates, each of which takes into account just one of the above ply characteristics (the weights add up to 1). That is, it is the sum of the following:

- Weighted flexibility rate (see formula)
- Weighted cutout rate (see formula)
- Weighted deformation rate (see formula)
- Weighted aspect rate (see formula)

You can generate a layup rate report by selecting **Reports > Spreadsheet Reports... > Composites Report**.

Weighted Flexibility Rate = Flexibility Weighting * Flexibility Rate

Weighted flexibility rate is the product of the following:

- Flexibility weighting: this reflects the relative importance of material flexibility to layup rate. It is a number between 0 and 1, specified by the cost model variable **weightingAFPMaterialFlexibility** (0.1 in starting point VPEs). Note that flexibility weighting, cutout weighting, deformation weighting, and aspect weighting must sum to 1.
- Flexibility rate: this is the layup rate, taking into account material flexibility.

Material flexibility is specified by the material property **Deformation Average Angle** (which is the average of **Deformation Limit Angle** and **Deformation Warning Angle**).

Flexibility rate is somewhere between the maximum rate (specified by the machine property **Max Deposition Rate**) and the minimum rate (1/6 the maximum rate, in starting point VPEs). If material flexibility is some fraction of the way from the easiest-to-handle flexibility to the hardest-to-handle flexibility (for available materials), then flexibility rate is that fraction of the way from the maximum rate to the minimum rate.

For example, if material flexibility is halfway between the easiest-to-handle flexibility and the hardest-to-handle flexibility, then flexibility rate is halfway between the maximum rate and the minimum rate.

Weighted Cutout Rate = Cutout Weighting * Cutout Rate

Weighted cutout rate is the product of the following:

- Cutout weighting: this reflects the relative importance of cutouts to layup rate. It is a number between 0 and 1, specified by the cost model variable **weightingAFPPLYCutout** (0.4 in starting point VPEs). Note that flexibility weighting, cutout weighting, deformation weighting, and aspect weighting must sum to 1.
- Cutout rate: this is the layup rate, taking into account ply cutouts.

The extent of cutouts is quantified by the *cutout ratio*, which is a ratio of geometric properties:

$$\text{Cutout Ratio} = \text{Surface Area} / \text{Surface Area Filled}$$

Surface Area Filled is the ply's area plus the estimated area of interior and perimeter cutouts.

Cutout rate is somewhere between the maximum rate (specified by the machine property **Max Deposition Rate**) and the minimum rate (1/6 the maximum rate, in starting point VPEs). If cutout ratio is some fraction of the way from the easiest-to-handle ratio to the hardest-to-handle ratio, then cutout rate is that fraction of the way from the maximum rate to the minimum rate.

For example, if cutout ratio is halfway between the easiest-to-handle ratio and the hardest-to-handle ratio, then cutout rate is halfway between the maximum rate and the minimum rate.

Weighted Deformation Rate = Deformation Weighting * Deformation Rate

Weighted deformation rate is the product of the following:

- Deformation weighting: this reflects the relative importance of deformation to layup rate. It is a number between 0 and 1, specified by the cost model variable **weightingAFPPLYDeformation** (0.3 in starting point VPEs). Note that flexibility weighting, cutout weighting, deformation weighting, and aspect weighting must sum to 1.
- Deformation rate: this is the layup rate, taking into account ply deformation.

The degree of deformation is quantified as a level between 1 and 5 (the higher the level, the greater the deformation). The level is determined based on the geometric properties **Average Curvature**, **Curvature Deviation**, and **Max Curvature**, and is intended to reflect a number of aspects of deformation, including the following:

- Degree of curvature: large curvature is harder to handle than mild curvature.
- Uniformity of curvature: varying curvature is harder to handle than overall, uniform curvature.
- Localization of curvature: distributed curvature (with multiple local extrema) is harder to handle than localized curvature.

See [Ply Deformation Level](#) for more information.

Deformation rate is somewhere between the maximum rate (specified by the machine property **Max Deposition Rate**) and the minimum rate (1/6 the maximum rate, in starting point VPEs). If deformation level is some fraction of the way from the easiest-to-handle level (1) to the hardest-to-handle level (5), then deformation rate is that fraction of the way from the maximum rate to the minimum rate.

For example, if deformation level is halfway between the easiest-to-handle level and the hardest-to-handle level, then deformation rate is halfway between the maximum rate and the minimum rate.

Weighted Aspect Rate = Aspect Weighting * Aspect Rate

Weighted aspect rate is the product of the following:

- Aspect weighting: this reflects the relative importance of aspect ratio to layup rate. It is a number between 0 and 1, specified by the cost model variable **weightingAFPANGLEVsAspect** (0.2 in starting point VPEs). Note that flexibility weighting, cutout weighting, deformation weighting, and aspect weighting must sum to 1.
- Aspect rate: this is the layup rate, taking into account ply aspect ratio.

Aspect ratio, here, is ply **Length** divided by ply **Width**. Note that **Length** is the dimension of the ply bounding box that is aligned with the ply direction. The cost model defines three aspect-ratio levels:

- Level 1 (fastest): aspect ratio $\geq 1 \frac{1}{3}$
- Level 2 (intermediate): $\frac{3}{4} < \text{aspect ratio} < 1 \frac{1}{3}$
- Level 3 (slowest): aspect ratio $\leq \frac{3}{4}$

Administrators can customize the level thresholds with the cost model variable **approxSquareRatio** (0.75 in starting point VPEs). The level thresholds are defined in terms of **approxSquareRatio** as follows:

- Level 1: aspect ratio $\geq 1 / \text{approxSquareRatio}$
- Level 2: $\text{approxSquareRatio} < \text{aspect ratio} < 1 / \text{approxSquareRatio}$
- Level 3: aspect ratio $\leq \text{approxSquareRatio}$

Aspect rate is somewhere between the maximum rate (specified by the machine property **Max Deposition Rate**) and the minimum rate (1/6 the maximum rate, in starting point VPEs). If aspect level is some fraction of the way from the fastest level (1) to the slowest level (3), then cutout rate is that fraction of the way from the maximum rate to the minimum rate.

For example, if aspect ratio level is halfway between the fastest level and the slowest level, then cutout rate is halfway between the maximum rate and the minimum rate.

Ply Material Cost =
(Ply Area / (Material Utilization / 100)) * Material Cost Per Unit Area

Material cost for a ply depends on the following:

- Ply area: specified by the geometric property **Surface Area**. This is the area of one side of the ply, before cutouts are removed.
- Material utilization: this is the percentage of ply material that is used in parts and is not wasted. It is specified by the material property **Material Utilization**.
- Material cost per unit area: unit cost of ply material, specified in square meters by the material property **Material Cost Per Area**. This is converted to cost per square millimeter for use in this formula.

Ply Deformation Level

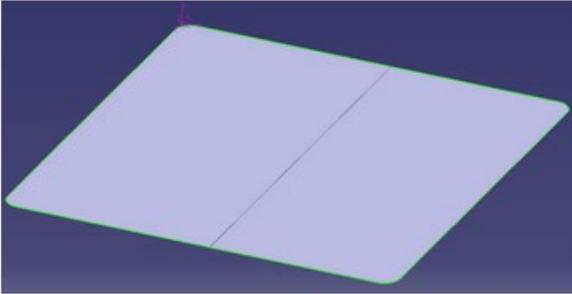
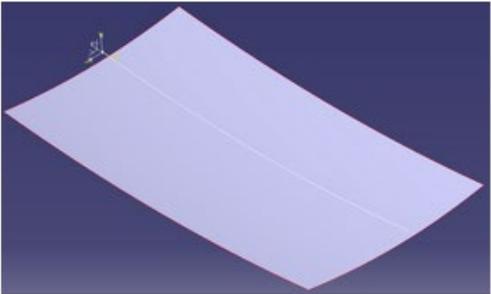
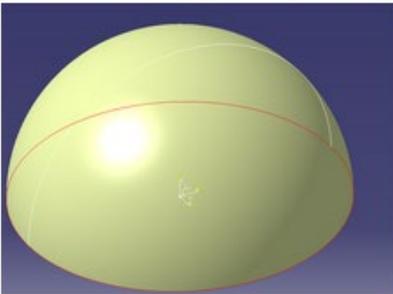
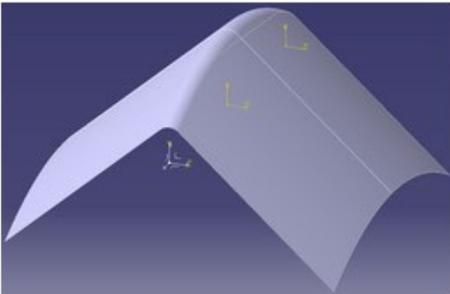
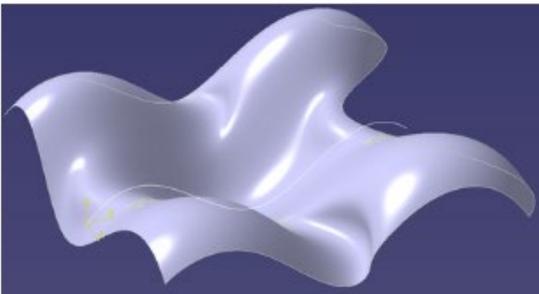
Ply deformation level is used to help determine layup rate--see [Ply Placing Operation for Hand Layup](#), [Ply Placing Operation for Automated Tape Layup](#), and [Ply Placing Operation for Automated Fiber Placement](#).

Deformation levels are intended to classify plies according to degree, uniformity, and localization of curvature:

- Level 1: flat
- Level 2: mild curvature
- Level 3: large but uniform curvature

- Level 4: large, non-uniform, but localized curvature
- Level 5: large, non-uniform, non-localized curvature

The following illustration shows various surfaces and their deformation levels:

Description	Representative Image	Deformation Level
Flat		1
Mild curvature		2
Large but uniform curvature		3
Large curvature but localised		4
Large curvature variable and distributed		5

A ply's deformation level is determined based on three geometric characteristics of the ply, which are expressed as dimensionless quantities:

- Total average curvature: this is the product of the GCD properties **Average Curvature** (average curvature per square millimeter) and **Surface Area Filled**.
- Total max curvature: this is the product of the GCD properties **Max Curvature** (maximum curvature per square millimeter) and **Surface Area Filled**.
- Total curvature standard deviation: this is the product of the GCD properties **Curvature Deviation** (standard deviation of curvature per square millimeter) and **Surface Area Filled**.

Deformation level is determined from these characteristics as follows, in starting point VPEs:

- Level 1: a ply has level 1 deformation if it is flat: total average curvature is 0.
- Level 2: otherwise, it has level 2 deformation if total average curvature is less than 1. In this case, curvature is considered small.
- Level 3: otherwise, it has level 3 deformation if total max curvature is less than 3 total curvature standard deviations away from total average curvature. In this case, curvature is considered large, but uniform. This is an application of the 3 sigma rule.
- Level: 4: otherwise, it is level 4 if less than 1% of the ply surface has curvature near **Max Curvature**. In this case, curvature is considered large and non-uniform, but localized.

The percentage of the surface that has curvature near **Max Curvature** is estimated as the ratio of total curvature variance (the square of total curvature standard deviation) to the square of the maximum total deviation (difference between total max curvature and total average curvature).

- Level 5: otherwise it has level 5 deformation. In this case, curvature is considered large, non-uniform, and non-localized.

VPE administrators can use the following cost model variables to customize these thresholds:

- **plyCurvatureMildThreshold** (1 in starting point VPEs): curvature is considered mild if total average curvature is less than this value.
- **plyCurvatureDeviationThreshold** (3 in starting point VPEs): curvature is considered uniform if total max curvature is less than this many standard deviations away from total average curvature.
- **plyCurvatureLocalizedThreshold** (0.01 in starting point VPEs): curvature is considered localized if the fraction of the ply surface that has curvature near **Max Curvature** is less than this value.

In terms of these cost model variables, deformation level is determined as follows:

- Level 1 if
Total Average Curvature = 0
- Otherwise, level 2 if

- Total Average Curvature < plyCurvatureMildThreshold.
- Otherwise, level 3 if
 Total Max Curvature – Total Average Curvature <
 Total Curvature Standard Deviation * plyCurvatureDeviationThreshold
- Otherwise, level 4 if
 Total Curvature Standard Deviation² /
 (Total Max Curvature – Total Average Curvature)² <
 plyCurvatureLocalizedThreshold.
- Otherwise, level 5

Autoclave Cure Process

Labor Time =

**(Labor Dependent Process Time * Labor Time Standard) +
Part Handling Labor Time**

Labor time depends on the following:

- Labor-dependent process time (see formula)
- Labor time standard: specified as the machine property **Labor Time Standard**. This multiplier is used to account for otherwise unaccounted for factors that affect labor time, such as operator fatigue or time spent by the operator for cleaning or maintenance.
- Part handling labor time (see formula)

Cycle Time =

**(Labor Independent Process Time +
(Labor Dependent Process Time / Number of Operators)) *
Cycle Time Adjustment Factor**

Cycle time depends on the following:

- Labor-independent process time (see formula)
- Labor-dependent process time (see formula)
- Number of operators: by default, this is specified by the machine property **Number of Operators**. Users can override the default on a per-part basis with the setup option **Number of Operators**.
- Cycle time adjustment factor: specified by the cost model variable **cycleTimeAdjustmentFactor** (1 in starting point VPEs). VPE administrators can change the cost model variable to globally adjust cycle times for Composites.

Labor Independent Process Time = Cure Time + Part Handling Elapsed Time

Labor-independent process time is the sum of the following:

- Cure time (see formula)
- Part handling elapsed time (see formula)

**Labor Dependent Process Time =
Thermocouple Connect Time +
Thermocouple Disconnect Time**

Labor dependent process time is the sum of the following:

- Part handling labor time (see formula)
- Thermocouple connect time (see formula)
- Thermocouple disconnect time: this is the same as thermocouple connect time (see formula)

Cure Time = Ramp Up Time + Dwell Time + Ramp Down Time

Cure time depends on the following:

- Ramp up time (see formula)
- Dwell time: this is the value of the material property **Cure Dwell Time** for the type of material with the longest **Cure Dwell Time** among those types of materials that are used by the part.
- Ramp down time (see formula)

**Ramp Up Time =
(Resin Cure Temperature – Resin Cure Ramp Up Start Temperature) /
Resin Temp Ramp Up Rate**

Ramp up time depends on the following:

- Resin cure temperature: this is the value of the material property **Cure Hold Temperature** for the type of material with the highest **Cure Hold Temperature** among those types of materials that are used by the part.
- Resin cure ramp up start temperature: specified by the cost model variable **resinCureRampUpStartTemperature** (30°C in starting point VPEs).
- Resin temp ramp up rate: this is the value of the material property **Cure Temperature Ramp Up Rate** for the type of material with the lowest **Cure Temperature Ramp Up Rate** among those types of materials that are used by the part.

**Ramp Down Time =
(Resin Cure Temperature – Resin Cure Ramp Up Start Temperature) /
Resin Temp Ramp Up Rate**

Ramp down time depends on the following:

- Resin cure temperature: this is the value of the material property **Cure Hold Temperature** for the type of material with the highest **Cure Hold Temperature** among those types of materials that are used by the part.
- Resin cure finish temperature: specified by the cost model variable **resinCureRampDownFinishTemperature** (40°C in starting point VPEs)
- Resin temp ramp down rate: this is the value of the material property **Cure Temperature Ramp Down Rate** for the type of material with the lowest **Cure Temperature Ramp Down Rate** among those types of materials that are used by the part.

Part Handling Labor Time = Part Handling Elapsed Time * Number of Operators

Part handling labor time is the product of the following:

- Part handling elapsed time (see formula)
- Number of operators: specified by the machine property **Number of Operators**.

Part Handling Elapsed Time = Part Load Time + Part Unload Time

- Part load time (see formula)
- Part unload time: specified by the cost model variable **moveIntoAutoclaveTime** (300 seconds in starting point VPEs).

Part Load Time = Move To Autoclave Cell Time + Move Into Autoclave Time

- Move to autoclave cell time: looked up by tool length and tool width in the **Tool Handling Time** column of the lookup table **tblHandlingTimes**.

Times		Part and Tool Dimensions	
Part Handling Time (s)	Tool Handling Time (s)	Box Length (mm)	Box Width (mm)
18.00	36.00	179.60	179.60
36.00	72.00	304.80	179.60
54.00	108.00	304.80	304.80
60.00	120.00	914.40	304.80
90.00	180.00	914.40	914.40
120.00	240.00	1,828.80	609.60
120.00	240.00	1,828.80	1,828.80
150.00	300.00	4,572.00	914.40
180.00	360.00	4,572.00	1,828.80
210.00	420.00	15,240.00	1,828.80
240.00	480.00	30,480.00	1,828.80
300.00	600.00	999,999,999.00	999,999,999.00

Tool length and width is estimated based on part length--see [Tool Length, Width, and Area](#).

- Move into autoclave time: specified by the cost model variable **moveIntoAutoclaveTime** (300 seconds in starting point VPEs).

Thermocouple Connect Time = Thermocouple Connection Rate * Thermocouples Total Num Required

Thermocouple connect time is the product of the following:

- Thermocouple connection rate: this is the time required to connect a single thermocouple to its sensor. It is specified by the cost model variable **thermocoupleConnectionRate** (20 seconds in starting point VPEs).
- Thermocouples total num required: this is the total number of thermocouples required for the part. By default it is calculated based on tool surface area (see

formula). Users can override the default with the setup option [Number of Thermocouples](#).

**Thermocouples Total Num Required =
roundup(Upper Surface Area of Part / Thermocouple Application Density)**

Thermocouple total num required depends on the following (by default—see [Number of Thermocouples](#)):

- Upper surface area of part: half the part's **Surface Area**.
- Thermocouple application density: specified by the cost model variable **thermocoupleApplicationDensity** (465,000mm² in starting point VPEs). This is the maximum upper surface area of the part that can be covered by an individual thermocouple.

Bench Operation Process

The Bench Operation process occurs twice in Composites routings. Each occurrence has a single, component-level, child operation:

- One occurrence includes the Tool Breakdown component-level operation, which models moving the part and tooling into the work cell, removing the vacuum bag and part, and moving the empty tooling out of the work cell.
- The other occurrence includes the Inspecting component-level operation, which models visually inspecting the finished part

**Labor Time =
(Labor Dependent Process Time * Labor Time Standard) +
Part Handling Labor Time**

Labor time depends on the following:

- Labor-dependent process time: this is the sum of the Labor Dependent Process Time for Tool Breakdown (vacuum bag removal) and the Labor Dependent Process Time for Inspecting (total inspection labor time). See [Tool Breakdown Component-level Operation](#) and [Inspecting Component-level Operation](#).
- Labor time standard: specified as the machine property **Labor Time Standard**. This multiplier is used to account for otherwise unaccounted for factors that affect labor time, such as operator fatigue or time spent by the operator for cleaning or maintenance.
- Part handling labor time (see formula)

**Cycle Time =
(Labor-independent Process Time +
(Labor Dependent Process Time / Number of Operators)) *
Cycle Time Adjustment Factor**

Cycle time depends on the following:

- Labor-independent process time: this is the value of the formula **Part Handling Time** for the [Tool Breakdown Component-level Operation](#).

- Labor-dependent process time: this is the sum of the Labor Dependent Process Time for Tool Breakdown (vacuum bag removal) and the Labor Dependent Process Time for Inspecting (total inspection labor time). See [Tool Breakdown Component-level Operation](#) and [Inspecting Component-level Operation](#).
- Number of operators: by default, this is specified by the machine property **Number of Operators**. Users can override the default on a per-part basis with the setup option [Number of Operators](#).
- Cycle time adjustment factor: specified by the cost model variable **cycleTimeAdjustmentFactor** (1 in starting point VPEs). VPE administrators can change the cost model variable to globally adjust cycle times for Composites.

Part Handling Labor Time = Part Handling Elapsed Time * Number of Operators

Part handling labor time is the product of the following:

- Part handling elapsed time: this is the value of the formula **Part Handling Time** for the [Tool Breakdown Component-level Operation](#).
- Number of operators: specified by the machine property **Number of Operators**.

Inspecting Component-level Operation

This operation models visually inspecting the finished part. This is an operation of the [Bench Operation Process](#). Inspection is assumed to be a labor-dependent task (see [Labor-dependent and Labor-independent Tasks](#)). Cycle time is given by the formula below.

**Cycle Time =
(Labor Dependent Process Time / Number of Operators) +
Labor Independent Process Time**

Cycle time depends on the following:

- Labor-dependent process time (see formula)
- Number of operators: by default this is specified by the machine property **Number of Operators**. Users can override the default with the setup option [Number of Operators](#).
- Labor-independent process time: this is the time to move the part to the work cell. By default, it is assumed that tool breakdown and inspecting occur at the same work station (see [Tool Breakdown Component-level Operation](#)). So this is 0 unless Tool Breakdown and Inspecting use different work cells (machines) as a result of manual machine selection. In such a case, labor-independent process time is given by the formula for Part Handling Time, below.

**Labor Dependent Process Time =
Component Surface Area / Final Inspection Rate**

- Component surface area: specified by the geometric property **Surface Area**.
- Final inspection rate: specified in area per unit time by the cost model variable **finalInspectionRate** (28,000mm²/sec in starting point VPEs).

**Part Handling Time =
Tool Load Time + Tool Unload Time**

Labor-independent process time is the sum of the following:

- Tool load time: looked up by tool length and tool width in the **Tool Handling Time** column of the lookup table **tblHandlingTimes**. Tool length and width is estimated based on part length--see [Tool Length, Width, and Area](#).
- Tool unload time: this is the same as tool load time.

Tool Breakdown Component-level Operation

This operation models moving the part and tooling into the work cell, removing the vacuum bag, removing the part from the tool, and moving the empty tooling out of the work cell. This is an operation of the [Bench Operation Process](#).

Cycle time is given by the formula below.

**Cycle Time =
(Labor Dependent Process Time / Number of Operators) +
Labor Independent Process Time**

Cycle time depends on the following:

- Labor-dependent process time: see formula.
- Number of operators: by default this is specified by the machine property **Number of Operators**. Users can override the default with the setup option [Number of Operators](#).
- Labor-independent process time: this is the time to move the part to the work cell. See the formula for Part Handling Time, below.

Labor Dependent Process Time = Part External Perimeter / Vacuum Bag Removal Rate

This is the time to remove the vacuum bag. It depends on the following:

- Part external perimeter: this is the length of the part's contours, excluding internal contours. It is specified by the geometric property **External Perimeter**.
- Vacuum bag removal rate: this is the rate in distance per unit time at which the edge of the vacuum bag is removed. It is specified by the cost model variable **vacuumBagRemovalRate** (300mm/sec in starting point VPEs).

**Part Handling Time =
Tool Load Time + Part Removal Time + Tool Unload Time**

Labor-independent process time is the sum of the following:

- Tool load time: looked up by tool length and tool width in the **Tool Handling Time** column of the lookup table **tblHandlingTimes**. Tool length and width is estimated based on part length--see [Tool Length, Width, and Area](#).

- Part removal time: by default, this is looked up by part **Length** and **Width** in the **Part Handling Time** column of the lookup table **tblHandlingTimes**. Users can override the default on a per-part basis with the setup option **Part Removal Time**.
- Tool unload time: this is the same as tool load time.

Tool Clean Process

Labor Time =
(Labor Dependent Process Time * Labor Time Standard) +
Part Handling Labor Time

Labor time depends on the following:

- Labor-dependent process time: this is the **Tool Cleaning Time** from the child operation. See [Manual Tool Cleaning Operation](#), [Cryogenic Tool Cleaning Operation](#), and [Laser Tool Cleaning Operation](#).
- Labor time standard: specified as the machine property **Labor Time Standard**. This multiplier is used to account for otherwise unaccounted for factors that affect labor time, such as operator fatigue or time spent by the operator for cleaning or maintenance.
- Part handling labor time: see formula

Cycle Time =
(Labor Independent Process Time +
(Labor Dependent Process Time / Number of Operators)) *
Cycle Time Adjustment Factor

Cycle time depends on the following:

- Labor-independent process time: this is elapsed handling time, looked up by tool length and tool width (see [Tool Length, Width, and Area](#)) in the **Tool Handling Time** column of the lookup table **tblHandlingTimes**.
- Labor-dependent process time: this is the **Tool Cleaning Time** from the child operation. See [Manual Tool Cleaning Operation](#), [Cryogenic Tool Cleaning Operation](#), and [Laser Tool Cleaning Operation](#).
- Number of operators: specified by the machine property **Number of Operators**.
- Cycle time adjustment factor: specified by the cost model variable **cycleTimeAdjustmentFactor** (1 in starting point VPEs). VPE administrators can change the cost model variable to globally adjust cycle times for Composites.

Part Handling Labor Time = Part Handling Elapsed Time * Number of Operators

Part handling labor time is the product of the following:

- Part handling elapsed time: looked up by tool length and tool width (see [Tool Length, Width, and Area](#)) in the **Tool Handling Time** column of the lookup table **tblHandlingTimes**.
- Number of operators: specified by the machine property **Number of Operators**.

Manual Tool Cleaning Operation

Manual tool cleaning is a labor-dependent task (see [Labor-dependent and Labor-independent Tasks](#)).

Cycle Time = Tool Cleaning Time / Number of Operators

Cycle time depends on the following:

- Manual tool cleaning time: this is the time it takes one operator to clean the tool. See formula.
- Number of operators (specified by the machine property **Number of Operators**)

Tool Cleaning Time = Tool Surface Area / Manual Tool Clean Rate

This is the time it takes one operator to clean the tool. It depends on the following:

- Tool surface area: this is estimated based on the part dimensions and a perimeter allowance. See formula.
- Manual tool clean rate: this the cleaning rate for one operator in area per unit time. It is looked up by tool surface area in the lookup table **tblManualToolCleanRates**.

Component Area (mm ²)	Manual Clean Rate (mm ² / s)
125,000.00	60,000.00
250,000.00	58,000.00
500,000.00	55,000.00
1,000,000.00	50,000.00
5,000,000.00	35,000.00
50,000,000.00	20,000.00
9,999,999,999,999.00	20,000.00

Additional Direct Costs =

Manual Cleaning Agent Cost Per Area * Tool Surface Area

This is the cost for the cleaning agent consumed in one cleaning of the tool. It is the product of the following:

- Material cleaning agent cost per area (see formula)
- Tool surface area: this is estimated based on the part dimensions and a perimeter allowance. See [Tool Length, Width, and Area](#).

Manual Cleaning Agent Cost Per Area =

Manual Cleaning Agent Cost Per Volume / Manual Cleaning Agent Coverage Rate Per Volume

Manual cleaning agent cost per area depends on the following:

- Manual cleaning agent cost per volume: specified by the tool shop variable **costPerVolume_manualCleaningAgent**.

- Manual cleaning agent coverage rate per volume: this is the area of mold covered by a given volume of cleaning agent, in area per unit volume. It is specified by the cost model variable **manualCleaningAgentCoverageRatePerVolume** (10,000,000mm/L in starting point VPEs).

Cryogenic Tool Cleaning Operation

Cycle Time = Tool Cleaning Time / Number of Operators

Cycle time depends on the following:

- Cryogenic tool cleaning time: this is the time it takes one operator to clean the tool. See formula.
- Number of operators (specified by the machine property **Number of Operators**)

Tool Cleaning Time = Tool Surface Area / Cryogenic Tool Clean Rate

This is the time it takes one operator to clean the tool. It depends on the following:

- Tool surface area: this is estimated based on the part dimensions and a perimeter allowance. See [Tool Length, Width, and Area](#).
- Cryogenic tool clean rate: this the cleaning rate for one operator in area per unit time. It is specified by the machine property **Clean Rate**.

Laser Tool Cleaning Operation

Cycle Time = Tool Cleaning Time / Number of Operators

Cycle time depends on the following:

- Laser tool cleaning time: this is the time it takes one operator to clean the tool. See formula.
- Number of operators (specified by the machine property **Number of Operators**)

Tool Cleaning Time = Tool Surface Area / Laser Tool Clean Rate

This is the time it takes one operator to clean the tool. It depends on the following:

- Tool surface area: this is estimated based on the part dimensions and a perimeter allowance. See [Tool Length, Width, and Area](#).
- Laser tool clean rate: this the cleaning rate for one operator in area per unit time. It is specified by the machine property **Clean Rate**.

Overhead Calculations for Composites

For each process, direct overhead cost per part are calculated with the following formulas:

**Direct Overhead Cost =
Labor Dependent Direct Overhead Cost +
Labor Independent Direct Overhead Cost**

Direct overhead cost per part is the sum of the following:

- Labor-dependent direct overhead cost: this is the direct overhead associated with labor-dependent tasks (see [Labor-dependent and Labor-independent Tasks](#)). See formula.
- Labor-independent direct overhead cost: this is the direct overhead associated with labor-independent tasks (see [Labor-dependent and Labor-independent Tasks](#)). See formula.

**Labor Dependent Direct Overhead Cost =
((Labor Cost * Overhead Multiplier) +
(Direct Overhead Rate * Labor Dependent Process Time)) /
Final Yield**

Labor-dependent direct overhead cost depends on the following:

- Labor cost: this is the value of the formula Labor Cost for the current process. See [Cost Algorithms and Calculations for Composites](#).
- Overhead multiplier: specified by the machine property **Overhead Multiplier** for the current process's machine.
- Direct overhead rate (see [Overhead Rates](#))
- Labor-dependent process time: for each process, this is the value of the formula Labor Dependent Process Time. See [Cost Algorithms and Calculations for Composites](#).
- Final yield (see [Yields for Composites](#))

**Labor Independent Direct Overhead Cost =
Machine Allocation Factor *
((Direct Overhead Rate * Labor Independent Process Time)) /
Final Yield**

Labor-independent direct overhead cost depends on the following:

- Machine allocation factor: this is the fraction of the machine used by a single part during a machine cycle. For most processes it is 1, because the machine is assumed to handle one part at a time. For Autoclave Cure in some cases, this fraction is calculated based on tool dimensions and machine dimensions (see [Shared Autoclave Capacity](#)).
- Direct overhead rate (see [Overhead Rates](#))
- Labor-independent process time: for each process, this is the value of the formula Labor Independent Process Time. See [Cost Algorithms and Calculations for Composites](#).
- Final yield (see [Yields for Composites](#))

User Inputs for Composites

Process setup options are covered in the following sections:

- Composites Node Option
- Ultrasonic Cut Options
- Mold Preparation Options
- Hand Layup Options
- Automated Tape Layup Options
- Automated Fiber Placement Options
- Autoclave Cure Options
- Bench Operation Options

Composites Node Option

The Composites node provides the following setup option:

- Number of Thermocouples

Number of Thermocouples

This is the total number of thermocouples required for the part. By default it is calculated based on tool surface area (see [Autoclave Cure Process](#)). Users can override the default with this setup option.

This value drives labor-dependent process time for the [Attach Thermocouples Component-level Operation](#) and the [Autoclave Cure Process](#).

Ultrasonic Cut Options

The Ultrasonic Cut process provides the following options:

- Raw Material Stack Count
- Cut Rate Override
- Number of Operators

Raw Material Stack Count

This is the number of plies that are assumed to be cut at the same time. By default in starting point VPEs, plies are assumed to be cut one at a time. VPE administrators can customize the default number of plies in a stack with the cost model variable **defaultRawMaterialStackCount** (1 in starting point VPEs). Users can override the default on a per-part basis with this setup option.

Stack count affects cut rate and cutting time—see [Ultrasonic Cutting Operation](#).

Cut Rate Override

By default in starting point VPEs, cut rate is specified by the machine property **Cut Rate**. If the number of plies in a stack is greater than 1 (see [Raw Material Stack Count](#)), the machine rate is decreased by the factor specified by the cost model variable **cuttingDerateFactor** (0.8 in starting point VPEs). Users can override the calculated cut rate with this setup option.

Cut rate drives cutting time—see also [Ultrasonic Cutting Operation](#).

Number of Operators

By default, the number of operators is specified by the machine property **Number of Operators**. With this setup option, users can override the default on a per-part basis.

Number of operators drives cycle time—see [Ultrasonic Cut Process](#).

Mold Preparation Options

The Mold Preparation process provides the following options:

- [Number of Mold Release Agent Coats](#)
- [Mold Release Agent](#)
- [Number of Operators](#)

Number of Mold Release Agent Coats

By default in starting point VPEs, the cost model assumes that three coats of mold release are applied to the tool during mold preparation. Administrators can customize the default number of coats with the cost model variable **defaultNumMoldReleaseCoats** (3 in starting point VPEs). Users can override the default with this setup option. See also [Routing and Feasibility for Composites](#).

This value drives cycle time, labor time, and additional direct costs (consumable material cost) for Mold Preparation—see [Applying Mold Release Operation](#) and [Curing Mold Release Operation](#).

Mold Release Agent

By default, the type of mold release agent to use for the current part is specified by the cost model variable **Default Tool Material Name (Generic Semi-Permanent Release Agent)** in starting point VPEs). Users can override the default on a per-part basis with this setup option. The options are taken from the tool shop **Tool Materials** table for this process.

The release agent type drives consumable material costs as well as cure times—see [Applying Mold Release Operation](#) and [Curing Mold Release Operation](#).

Number of Operators

By default, the number of operators is specified by the machine property **Number of Operators**. With this setup option, users can override the default on a per-part basis.

Number of operators drives cycle time—see [Mold Preparation Process](#).

Hand Layup Options

The Hand Layup process provides the following options:

- Number of Ply Sequences Before First Debulk
- Number of Ply Sequences Per Debulk Cycle
- Number of Operators
- Layup Tool Cost Override
- Layup Tool Material
- Number of Holes Potted in Honeycomb Core
- Total Length of Honeycomb Core Splicing
- Part Rough Mass

Number of Ply Sequences Before First Debulk

By default in starting point VPEs, the first placement cycle (before the first Debulk) consists of a single occurrence of the Ply Placing operation. Administrators can customize this default with the cost model variable **defaultNumPliesBeforeFirstDebulk** (1 in starting point VPEs). Users can override the default on a per-part basis with this setup option. See also [Routing and Feasibility for Composites](#).

Number of Ply Sequences Per Debulk Cycle

Subsequent to the first ply placement cycle, each ply placement cycles consists of three occurrences of the Ply Placing operation, by default in starting point VPEs. Administrators can customize this default with the cost model variable **defaultNumPliesPerDebulkCycle** (3 in starting point VPEs). Users can override the default on a per-part basis with this setup option. See also [Routing and Feasibility for Composites](#).

Number of Operators

By default, the number of operators is specified by the machine property **Number of Operators**. With this setup option, users can override the default on a per-part basis. Number of operators drives cycle time—see [Hand Layup Process](#).

Layup Tool Cost Override

By default, hard tooling cost is calculated based on the following:

- Tool material cost (looked up by the current tool material in the **Layup Tool Cost Per Area** column of the tool shop **Tool Materials** table--see [Layup Tool Material](#)),
- Tool surface area (see [Tool Length, Width, and Area](#))
- Tool shop variable **Region Multiplier**.

With this setup option, users can override the default on a per-part basis, and specify the tool cost explicitly. See also [Tooling for Composites](#).

Layup Tool Material

By default, tool material is specified by the tool shop variable **Default Tool Material Name**. Users can override the default on a per-part basis with this setup option. The following options are available:

- Aluminum
- Invar
- Steel

The options are taken from the tool shop **Tool Materials** table for this process.

This value drives tool cost—see [Tooling for Composites](#).

Number of Holes Potted in Honeycomb Core

Potting is required for core regions that contain fastener holes. Potting stiffens such core regions by injecting low-density material, which hardens during curing, and prevents crushing during fastening. Fastener holes are not typically modeled in CAD.

By default in starting point VPEs, the total number of the part's fastener holes is assumed to be 0. Administrators can customize the default with the cost model variable **defaultNumCorePottingRequired**. Users can override the default on a per-part basis with this setup option.

This value drives times and consumable material costs for Hand Layup—see [Core Potting Operation for Hand Layup](#).

Total Length of Honeycomb Core Splicing

This setup option specifies the total length of the butt joints formed by core splicing for the whole part. This value drives times and consumable material costs for Hand Layup—see [Core Splicing Operation for Hand Layup](#). By default in starting point VPEs, this is assumed to be 0. Administrators can customize the default with the cost model variable **defaultCoreSpliceLength**. Users can override the default on a per-part basis with this setup option.

Core splicing is required when a core must be formed by splicing together two or more other cores (which may not be individually modeled in CAD). Splicing uses foaming adhesive to form butt joints.

Part Rough Mass

By default, the part rough mass is assumed to be the same as the finish mass—the sum of the ply masses (excluding holes) and core masses (if any). If secondary machining will remove significant mass for a particular part, you can specify the mass prior to removal with this setup option. This can increase the accuracy of handling time estimates for machining.

Automated Tape Layup Options

The Automated Tape Layup process provides the following options:

- Layup Tool Cost Override

- Layup Tool Material
- Automated Tape Layup Machine Programming Cost
- Number of Operators
- Part Rough Mass

Layup Tool Cost Override

By default, hard tooling cost is calculated based on the following:

- Tool material cost (looked up by the current tool material in the **Layup Tool Cost Per Area** column of the tool shop **Tool Materials** table--see [Layup Tool Material](#)),
- Tool surface area (see [Tool Length, Width, and Area](#))
- Tool shop variable **Region Multiplier**.

With this setup option, users can override the default on a per-part basis and specify the tool cost explicitly. See also [Tooling for Composites](#).

Layup Tool Material

By default, tool material is specified by the tool shop variable **Default Tool Material Name**. Users can override the default on a per-part basis with this setup option. The following options are available:

- Aluminum
- Invar
- Steel

The options are taken from the tool shop **Tool Materials** table for this process.

This value drives tool cost—see [Tooling for Composites](#).

Automated Tape Layup Machine Programming Cost

By default, cost to program the layup machine is specified by the cost model variable **defaultATLProgrammingCost** (0 in starting point VPEs). Users can override the default on a per-part basis with this setup option.

This value contributes to capital investment. See [Automated Tape Layup Process](#).

Number of Operators

By default, the number of operators is specified by the machine property **Number of Operators**. With this setup option, users can override the default on a per-part basis. Number of operators drives cycle time—see [Automated Tape Layup Process](#).

Part Rough Mass

By default, the part rough mass is assumed to be the same as the finish mass—the sum of the ply masses (excluding holes). If secondary machining will remove significant mass for a particular part, you can specify the mass prior to removal with this setup option. This can increase the accuracy of handling time estimates for machining.

Automated Fiber Placement Options

The Automated Fiber Placement process provides the following options:

- Layup Tool Cost Override
- Layup Tool Material
- Automated Fiber Placement Machine Programming Cost
- Number of Operators
- Number of Active Spools
- Part Rough Mass

Layup Tool Cost Override

By default, hard tooling cost is calculated based on the following:

- Tool material cost (looked up by the current tool material in the **Layup Tool Cost Per Area** column of the tool shop **Tool Materials** table--see [Layup Tool Material](#)),
- Tool surface area (see [Tool Length, Width, and Area](#))
- Tool shop variable **Region Multiplier**.

With this setup option, users can override the default on a per-part basis and specify the tool cost explicitly. See also [Tooling for Composites](#).

Layup Tool Material

By default, tool material is specified by the tool shop variable **Default Tool Material Name**. Users can override the default on a per-part basis with this setup option. The following options are available:

- Aluminum
- Invar
- Steel

The options are taken from the tool shop **Tool Materials** table for this process.

This value drives tool cost—see [Tooling for Composites](#).

Automated Fiber Placement Machine Programming Cost

By default, cost to program the layup machine is specified by the cost model variable **defaultAFPProgrammingCost** (0 in starting point VPEs). Users can override the default on a per-part basis with this setup option.

This value contributes to capital investment. See [Automated Fiber Placement Process](#).

Number of Operators

By default, the number of operators is specified by the machine property **Number of Operators**. With this setup option, users can override the default on a per-part basis. Number of operators drives labor-dependent process time—see [Automated Fiber Placement Process](#).

Number of Active Spools

This is the number of active spools. By default, it is determined based on machine properties and the material width of that ply (among all the part's plies) that has the largest value for the material property **Material Width**. For more information, see **Number of Spools** in [Ply Placing Operation for Automated Fiber Placement](#). Users can override the default with this setup option.

This value drives layup rate as well as the number of course changes, both of which drive layup time. See [Ply Placing Operation for Automated Fiber Placement](#).

Part Rough Mass

By default, the part rough mass is assumed to be the same as the finish mass—the sum of the ply masses (excluding holes) and core masses (if any). If secondary machining will remove significant mass for a particular part, you can specify the mass prior to removal with this setup option. This can increase the accuracy of handling time estimations for machining.

Autoclave Cure Options

The Autoclave Cure process provides the following options:

- [Number of Operators](#)
- [Shared Autoclave Capacity](#)

Number of Operators

By default, the number of operators is specified by the machine property **Number of Operators**. With this setup option, users can override the default on a per-part basis.

Number of operators drives cycle time—see [Autoclave Cure Process](#).

Shared Autoclave Capacity

This setup options specifies whether multiple parts can potentially share the Autoclave machine during a cycle. By default in starting point VPEs, it is set to **true**. In this case, the fraction of the machine occupied by a single part during a machine cycle is calculated based on tool dimensions and machine dimensions:

Fraction = Tool Surface Area / Autoclave Area Capacity

This fraction is the **Machine Allocation Factor** used in [Overhead Calculations for Composites](#). It depends on the following:

- Tools surface area: see [Tool Length, Width, and Area](#).
- Autoclave area capacity: see formula.

Autoclave Area Capacity =

$$\text{(Machine Usable Length * Autoclave Size Capacity Safety Factor) * (Machine Useable Diameter * Autoclave Size Capacity Safety Factor)}$$

Autoclave area capacity depends on the following:

- Machine usable length: specified by the machine property **Usable Length**.
- Machine usable diameter: specified by the machine property **Usable Diameter**.
- Autoclave size capacity safety factor: specified by the cost model variable **autoclaveSizeCapacitySafetyFactor** (0.8 in starting point VPEs).

VPE administrators can customize the default behavior, and specify that a single part occupies the machine during a given cycle, by setting the cost model variable **autoclaveIsShared** to **false**. With this setup option, users can override the default on per-part basis.

Note: Users can also override the machine allocation factor by changing the value in the Autoclave Cure process' custom outputs. But they should take care to specify a value between 0 and 1 (these bounds are *not* enforced by aPriori). The override is applied regardless of the setting of this setup option.

Cost Object			Custom Outputs	
Status	Name	Scenario	Output Name	Output Value
● *	Current	Initial	You can change Machine Allocation Factor in Custom Outputs	
●	Composites		Enter a value between 0 and 1 (these bounds are not enforced by aPriori).	
●	Ultrasonic Cut			
●	Mold Preparation			
●	Hand Layup			
●	Autoclave Cure			
			The override takes effect regardless of the setting of the PSO Shared Autoclave Capacity	
			Cure Time (min)	355.00
			Autoclave Is Shared With Other Parts	true
			Machine Allocation Factor	0.17
			Total Number of Thermocouples Used	2.00

Bench Operation Options

The Bench Operation Process and the Tool Breakdown component-level operation provide the following options:

- Number of Operators
- Part Removal Time

Number of Operators

(Provided by the Bench Operation process.)

By default, the number of operators is specified by the machine property **Number of Operators**. With this setup option, users can override the default on a per-part basis. Number of operators drives cycle time—see [Inspecting Component-level Operation](#) and [Tool Breakdown Component-level Operation](#).

Part Removal Time

(Provided by the Tool Breakdown component-level operation.)

This is the time to remove the part from tool after curing. By default, this time is looked up by part **Length** and **Width** in the **Part Handling Time** column of the lookup table **tblHandlingTimes**. Users can override the default on a per-part basis with this setup option.

Part removal time is a component of labor-dependent process time. See [Tool Breakdown Component-level Operation](#).

9 Forging Process Group

This chapter describes the costing details and inputs that are available for the Forging process group.

This chapter includes the following topics:

- Forging overview
 - Forging processes
 - Forging material
 - Forging machines
 - Forging process routings
 - Forging process setup
 - Forging costing details
-

Forging overview

The Forging process group enables estimation of manufacturing times and costs for several Closed Die Forging processes, as well as subsequent machining, optional heat treatment, surface treatment, and packaging processes, if your company has licensed these modules. The process model also includes estimates for the costs of necessary tooling.

Forging processes

The (closed die) Forging processes available in aPriori include:

- Saw
- Preheat
- Hammer (Upsetting, Blocking/Roughing, Finishing)
- Press (Piercing)
- Trim

By default, the Hammer process assumes that Upsetting, Blocking (roughing), and Finishing hits all are performed and computes the number of hits of each type required to manufacture the part. However, this information can be overridden by you (see *Forging process setup on page 492*). Hammer tooling cost estimates include the costs of upsetting die cavities (if enabled), blocking die cavities (if enabled), and finishing die cavities.

Forging material

The Forging process group supports the use of either round bar stock or square bar stock only. By default, aPriori uses an algorithm for selecting suitable Forging material stock sizes that requires that the ratio of stock height to stock diameter/width is within a specified range. The goal of this algorithm is to select a stock that will undergo sufficient deformation to result in the desired material properties once forged (e.g., increased density and increased strength due to improved grain structure), but also avoid buckling during the forging process. The algorithm first determines a set of suitable stock diameters/widths, based on final part dimensions and volume, and then selects a set of suitable corresponding stock lengths based on the ratio-range requirement. Finally, aPriori chooses the specific stock size with the largest diameter/width that meets the ratio requirement. However, other stock sizes that also meet the ratio-range requirement are available for user-selection if desired.

If you wish to view or change the material composition, stock size selected, or material utilization computation, use the Material Selection window. For more information, see the "Selecting Material" section of the aPriori *User Guide*.

If you wish to have more visibility into the forging stock selection details, or affect the set of suitable stocks selected by modifying the range of acceptable stock height to diameter/width values that are used in the forging stock selection algorithm, see *Controlling forging stock selection on page 490*.

Forging material composition

Forging Material composition details include:

- Material
- Description
- Material Type
- Material Cut Code
- Density (kg/m³)
- Shear Strength (MPa)
- Unit Cost Per Mass (\$/kg, for square bar and round bar stock forms). This value is used to cost Virtual Stock and tends to be somewhat higher than the average cost of the actually available stock sizes in that material and cross section.

Forging material stocks

Material stock details include:

- Name
- Description
- Stock Form
- Dimensions (dependent on stock form)
- Width (mm)
- Height (mm)
- Outside diameter (mm)
- Inside diameter (mm)
- Wall thickness (mm)
- Length (mm)
- Cost Per KG (\$/kg)

Note This is the Unit Cost of the actual stock item in this size. It typically will differ somewhat from the Unit Cost of the virtual stock in the Material Composition table.

Controlling forging stock selection

The Forging process group displays some outputs that can be useful for determining if the stock selected is sufficient for the part.

To see these outputs

- 1 Open/view the Part Details tab
- 2 In the left-most column, expand the Forging process group node and then expand the Material Stock process node.

- 3 Scroll to the right to see the Custom Outputs column, which will display details of the “mult” from which the final part is forged. (A long piece of stock is cut into mults, each of which is forged into a single part).

Material Stock custom outputs include:

- Height Width ratio
- Mult Length
- Mult Width
- Mult Mass
- Mult Volume

If you wish to change the stock sizes determined to be suitable for forging a part, this can be accomplished by a VPE Administrator. The plant variables minBilletRatio and maxBilletRatio define the range of acceptable height-to-diameter/width ratios used in the stock selection algorithm. Contact aPriori Support for more information.

Forging material utilization

You can indicate how to determine Forging material utilization. Material utilization options include:

- Computed — aPriori calculates material utilization using an algorithm specific to the Forging process group
- Machine Default — aPriori calculates material utilization using a utilization percentage value specified for the selected machine (in the case of Forging, this is the material stock “machine”).
- Override — aPriori calculates material utilization using a utilization percentage value entered by you.

By default, aPriori uses the Computed option.

Forging machines

The aPriori Baseline VPE contains multiple Bandsaw machines, multiple Hammer machines, and three Preheat ovens (small, medium, and large). There is a single default Piercing press and a single default Trim press, since these presses are present in the same workcell as the selected Hammer and not chosen independently. By default, for each forging process, aPriori selects lowest-cost machine with the capability or capacity for the part(s) being manufactured. For example, it will select the lowest cost Hammer with sufficient impact energy to forge the part). You can manually select a different machine than the one selected by aPriori by using the Edit Machine Selection window which lists the properties of all machines available at the facility. For information on how to select a different machine, see the "Selecting a machine for an operation" section of the aPriori *User Guide*.

Forging process routings

The aPriori Baseline VPEs currently provide a single closed-die Forging routing.

If the Machining process group has been licensed, Forging routings may include 3-Axis and 4-Axis Milling operations, Drill Press operations, Cylindrical Grinding operations, and (if helical groove geometry is present) Single Index Milling and Rotor Grinding operations. If the optional Turning module also has been licensed, routings also can include turning processes (2-axis, 3-axis, 4-axis, and 6-axis lathes). For complete details about machining, see *Stock Machining and Machining Process Groups* on page 495.

Forging routings may include a variety of heat-treatment and finishing operations. The routing also includes subsequent optional surface treatment and packaging processes, if your customer has licensed these modules.

Forging process setup

For Forging, you can specify the following types of process options:

- Top-level setup options
- Material stock setup options
- Hammer setup options
- Piece press setup options
- Trim setup options

Top-level setup options

The Forging routing node provides the following setup options:

- **Enable Scrap Material Credit:** By default in starting point VPEs, the cost model assumes that material scrap (for example, trim scrap) is *not* sold for credit. Administrators can customize the default with the cost model variable **enableScrapMaterialCredit** (**false** in starting point VPEs). With this setup option, users can override the default on a per-part basis.

Enabling scrap material credit increases material utilization and decreases material cost. The credit rate is specified as a percentage of the material rate by the material property **Scrap Cost Percent**.

- **Enable Scrap Part Credit:** By default in starting point VPEs, the cost model assumes that the material from scrapped parts is *not* sold for credit. Administrators can customize the default with the cost model variable **enableScrapPartCredit** (**false** in starting point VPEs). With this setup option, users can override the default on a per-part basis.

Enabling scrap part credit increases material utilization and decreases material cost. This includes credit for parts scrapped by this process as well as by downstream processes. The credit rate is specified as a percentage of the material rate by the material property **Scrap Cost Percent**.

Material stock setup options

There are two setup options available by right-clicking on the Material Stock process in the manufacturing tree or process routing editor:

- Material added per surface for forging

By default, aPriori determines the forging mult volume based on the dimensions of the finished part, in part using an “offset” value that is automatically computed. Users can override this offset value if desired.

- Orientation of bar stock

This process setup option has three radio-button settings:

Let aPriori Decide

Upright: stock axis is parallel with part draw direction

Flat: stock axis is perpendicular to part draw direction

By default, “Let aPriori Decide” is selected, and aPriori determines the default stock orientation by evaluating the finished part’s length and width. Parts with high length-to-width ratios (that is, relatively long thin parts) will have a flat orientation by default (with the stock length/axis perpendicular to the part draw dimension). Parts with low ratios (that is, relatively short, wider parts) will have an upright orientation by default (with the stock length/axis parallel with the part draw dimension). aPriori displays the chosen orientation in square brackets [] following this radio button option. By default, the threshold value for the length-to-width ratio is 3, but this can be configured by your System Administrator. aPriori will display the chosen orientation immediately following that radio button.

You also can explicitly choose the orientation using either the Flat or Upright radio buttons. If you wish to have aPriori resume determining the stock orientation for the part, then re-select the “Let aPriori Decide” radio button.

Hammer setup options

There are two types of setup options available for the Hammer process:

- Upsetting, Blocking, and Finishing options –

By default, aPriori assumes that a 3-cavity die is used for each part and the Hammer performs Upsetting hits, Blocking hits, and Finishing hits. It also automatically computes the number of hits of each type required to produce the part. Users can indicate whether Upsetting and Blocking hits are performed, and also override the number of hits of each type.

Note The number of hits of each type also are output on the Part Details tab, as Custom Outputs for the Hammer process. This can be a useful way to inspect values computed by aPriori.

- Number of Hammer Operators –

By default, aPriori assumes that 2 operators are required for the Hammer process. You can override this value if desired. This will affect process labor costs.

Piece press setup options

There is one setup option available for the (Pierce) Press process:

- Number of Pierce Press Operators –

By default, aPiori assumes that 1 operator is required for the Pierce Press process. You can override this value if desired. This will affect process labor costs.

Trim setup options

There is one setup option available for the Trim process:

- Number of Trim Press Operators –

By default, aPiori assumes that 1 operator is required for the Trim press process. You can override this value if desired. This will affect process labor costs.

Forging costing details

The Forging process group uses the following costing rules:

- The aPiori Baseline VPEs assume that only a single part is forged at one time. This affects part cycle times and costs, as well as tooling costs.
- Tooling costs are computed for Hammer, Piercing Press, and Trim Press processes.
- By default, for each forging process, aPiori selects lowest-cost machine with the capability or capacity for the part(s) being manufactured. For example, it will select the lowest cost Hammer with sufficient impact energy to forge the part).
- If machining processes are included as secondary processes on forged components, then the machining costs are computed via the Machining cost model and combined with the Forging process costs to produce a total manufacturing process cost.

10 Stock Machining and Machining Process Groups

This section describes the costing details and inputs that are available for the Stock Machining and Machining process groups.

This chapter includes the following topics:

- Machining Overview
 - Material Stock and Utilization
 - GCD Extraction
 - Routing and Feasibility for Machining
 - Cost Algorithms and Calculations
 - User Inputs
 - Design-to-cost Configuration for Machining
 - Semi-automated Costing
 - Working with Features to Review
 - Working with the Heat Map
 - Modifying Machining Operation Assignments
 - Working with Gears, Splines, Sprockets, and Flutes
 - Working with Part Setups and SetupAxis GCDs
 - Setup Axes and Operation Feasibility
-

Machining Overview

Machining functionality is organized into two process groups: the Stock Machining process group and the Machining process group. The Stock Machining process group includes processes and material sizing and selection logic specific to parts being fully machined from round or rectangular stock. The majority of machining processes are actually organized under the Machining process group, so that they may be combined with either Stock Machining processes (for fully-machined parts), or with processes in the 2-Model, Casting, Forging, Sheet Metal, Powder Metal, Bar & Tube Fabrication and Assembly process groups to compute estimates for manufacturing that spans these operations. The processes are organized this way only to maximize flexibility and to avoid redundancy; for practical purposes, you can think of these processes as belonging to the same process group.

Note Stock Machining should be chosen as the primary process groups for fully-machined parts, rather than the Machining process group. The Machining process group cannot be used as a primary process group.

Machining processes are organized into the following separately-licensed modules:

- Milling, which includes
 - 3-Axis Mill
 - 4-axis Mill
 - 5-axis Mill
 - Stock Prep Mill
 - Sawing/cut-to-length processes
 - Wire EDM
 - Automated Deburr
 - Manual Deburr
- Turning, which includes
 - 2-Axis Lathe
 - 3-Axis Lathe
 - 2-Axis Bar Feed Lathe with Sub Spindle
 - 3-Axis Bar Feed Lathe with Sub Spindle
 - Mill Turn
 - Stock Prep Lathe
- Drilling, which includes
 - Gun Drill
 - Drill Press
 - Deep Bore Machine
- Gear Making, which includes
 - Broach
 - Hobbing
 - Shaping
 - Shaving

- Bevel Gear Cutting
- Grinding, which includes
 - OD grinding processes
 - ID grinding processes
 - Surface grinding processes
 - Rotor Grinder
 - Gear grinding processes

The Stock Machining process group includes the following processes:

- **Material Stock:** accounts for any specified stock allowances and estimates the size and cost of stock needed to fully machine the part from bar stock, as well as the resulting material utilization. It is not a physical machining process.
- **Band Saw:** estimates the time and cost of cutting bar stock to length.

The Machining process group also supports secondary Chemical Milling for soft-tooled sheet metal parts—see [Chemical Milling](#).

You can incorporate the use of aPriori's diagnostic tools into your costing workflow, including aPriori's Heat Map and Features to Review listing. See [Working with the Heat Map](#) and [Working with Features to Review](#). In addition, advanced users can use the diagnostic tools in conjunction with the semi-automated costing workflow—see [Semi-automated Costing](#).

aPriori includes special support for recognizing, defining, and costing gears. See [Working with Gears, Splines, Sprockets, and Flutes](#).

Material Stock and Utilization

The Stock Machining process group allows you to edit and view values for:

- Stock Machining Material Composition
- Stock Machining Material Stock Type
- Material Stock Alignment and Cross-section Determination
- Stock Machining Material Stock Allowances
- Stock Machining Material Utilization

Stock Machining Material Composition

Material composition details include:

- Material
- Description
- Mode
- Material Type Name
- CMC Cut Code (using the Sandvik-Coromant Material Classification system)
- Cost Per Mass (\$/kg)
- Density (kg/m³)

- Shear Strength (MPa)
- Hardness
- Hardness System
- Milling Speed
- Turning Speed

Stock Machining Material Stock Type

Material stock types include:

- Round Bar
- Rectangular Bar
- Plate
- Square Bar
- Round Tube

Material stock details include:

- Stock Name
- Description
- Stock Form (Round Bar, Rectangular Bar, Plate, Square Bar, or Round Tube)
- Stock Dimensions (dependent on stock form, e.g. Length (mm), Width (mm), Thickness (mm), Outer Diameter (mm), Inner Diameter)
- Cost Per Mass (\$/kg)
- Hardness
- Hardness System

Material Stock Alignment and Cross-section Determination

When costing a part, aPriori automatically determines the most likely stock form and alignment direction. To do this, it analyzes the geometry of the part and evaluates potential stock axis directions and cross-sections from these directions. To view the chosen stock cross section, click the  Stock Form and Alignment button in the Component Viewer tool bar.

To choose a different stock form or align the stock differently, use the Stock Form and Alignment tool in the Component Viewer. For more information, see the "Defining stock form and alignment for the Stock Machining and Bar & Tube process groups" section of the aPriori *User Guide*.

Note Changing material stock form and alignment may affect material utilization.

Round parts are generally assigned a round cross-section (allowing the selection of round stock). But for parts that are, roughly speaking, flat and round, geometry extraction assigns a rectangular cross-section (and may select plate stock). Parts are considered flat and round, in this sense, if both the following hold:

- Part's round cross-section diameter is greater than or equal to the value of the site variable **maxRoundStockDiameterMm** (304.8mm in starting points).
- Ratio of part thickness to round cross-section diameter is less than or equal to the value of the site variable **maxRoundStockAspectRatio** (0.2 in starting points).

If either of these site variables is -1, aPriori may select the round cross-section rather than the rectangular one.

In starting point VPEs, plate stock is auto-selected by aPriori only if the part width is greater than 142.4mm and the height-to-width ratio is less than 0.25. VPE administrators can customize these thresholds with the cost model variables **minPlateTriggerWidth** and **maxPlateTriggerHeightOverWidth**.

Stock Machining Material Stock Allowances

aPriori supports the concept of a machining stock allowance when determining the initial stock size required to machine a given part. A stock allowance typically is a small amount of extra material added to the finished part dimensions to accommodate any machining (material removal) needed to meet material quality, tolerance or surface finish requirements. A non-zero stock allowance is necessary to drive rough- and finish-machining of the part. A zero-value stock allowance means that the “as-supplied” stock surfaces are sufficient for the finished part, with no additional machining required to achieve desired quality, tolerances or surface finish requirements.

aPriori computes the ideal stock size required for a part based on the following:

- Dimensions of the finished part
- Amount of material required to meet any specified stock allowances

In general, by default in starting point VPEs, aPriori selects actual stock with the smallest standard thickness greater than or equal to the ideal thickness (and only selects virtual stock if there is no such actual stock). The setup option Stock Unit System (see [Material Stock Options](#)) determines whether aPriori uses metric standard stock heights or US standard stock heights.

You can override the default behavior and direct aPriori to select virtual stock if there is no actual stock with ideal thickness—see the process setup option **Snap Up to a Standard Stock Height** in [Material Stock Options](#). VPE administrators can change a VPE's default stock-selection behavior with the cost model variable **snapStockSize** (which is **true** in aPriori starting point VPEs). See [Material Stock Options](#) for more information.

For plate stock, if Roughing Technique is set to Plate Cutting with Dropoff (see [Stock Machining Node Process Setup Option](#)), the stock width and length are equal to the standard width and length specified by the cost model variables **standardPlateLength** and **standardPlateWidth** (4 feet and 8 feet, respectively, in aPriori starting point VPEs)—assuming the part width and length are less than the standard width and length. If the part width and length are greater than the standard, then virtual stock is created that is part width and length plus stock allowances.

Each VPE specifies default values for:

- Face Stock Allowance - the default allowance on each “end face” of the bar stock, or equivalently in the Length-wise direction of the stock (relevant for all stock forms)

- Outer Diameter (OD) and Inner Diameter (ID) stock allowances (for round bar and round tube stock forms)
- Width Direction and Height Direction stock allowances (for rectangular stock).

The aPriori starting point VPEs assume non-zero stock allowances for all directions except for the ID stock allowance, which is set to zero.

aPriori also provides process setup options to enable you to override the default stock allowance values for any given part or assembly. To specify a non-default stock allowance value, right-click on the Material Stock process in the Manufacturing Process pane and select Process Setup Options... A window will appear allowing you to edit any or all of the default stock allowance values. See [Material Stock Options](#) for more information.

Stock Machining Material Utilization

Material utilization options include:

- Computed — aPriori computes the utilization based on comparing the finished size of the part to the size of the starting material stock.
- Machine Default — aPriori uses the selected machine's default utilization value.
 - Override — aPriori calculates initial material mass and cost by dividing part finished mass by a user-entered utilization rate.

For more information on selecting the machining material utilization mode, see [Manufacturing Process Information > Selecting material > Change material utilization](#) in the aPriori *User Guide*.

Stock Machining Routing and Plate Stock

When plate stock is selected for stock machining, the Perimeter Cutting process from the machining process group is assigned to the part if both the following hold:

- The setup option **Roughing Technique** is **Plate Cutting with Dropoff** (see [Stock Machining Node Process Setup Option](#)).
- Perimeter extraction is enabled (see [Perimeter GCD](#)).

Bulk milling and perimeter milling are also available—see [Stock Machining Node Process Setup Option](#).

The Perimeter Cut operation is assigned to sufficiently large perimeter GCDs whose surfaces are parallel to the thickness direction of the stock.

By default, this operation is implemented by Waterjet Cut in the Sheet Metal process group; Plasma Cut, Oxyfuel Cut, and Laser Cut (also from the Sheet Metal process group) are available for manual selection. See [Sheet Metal—Soft Tooled](#).

GCD Extraction

Some of the important GCD types are listed in this section. Many of them have associated site variables, described here, that you can use to customize GCD extraction.

- Component GCD

- Hole GCD
- Parallel Surface Chain GCD
- Perimeter GCD
- LIES_NEAR Relation
- IS_ABOUT Relation
- IS_FILLET_OF Relation
- CorssSection GCD
- Pocket GCD
- Slot GCD

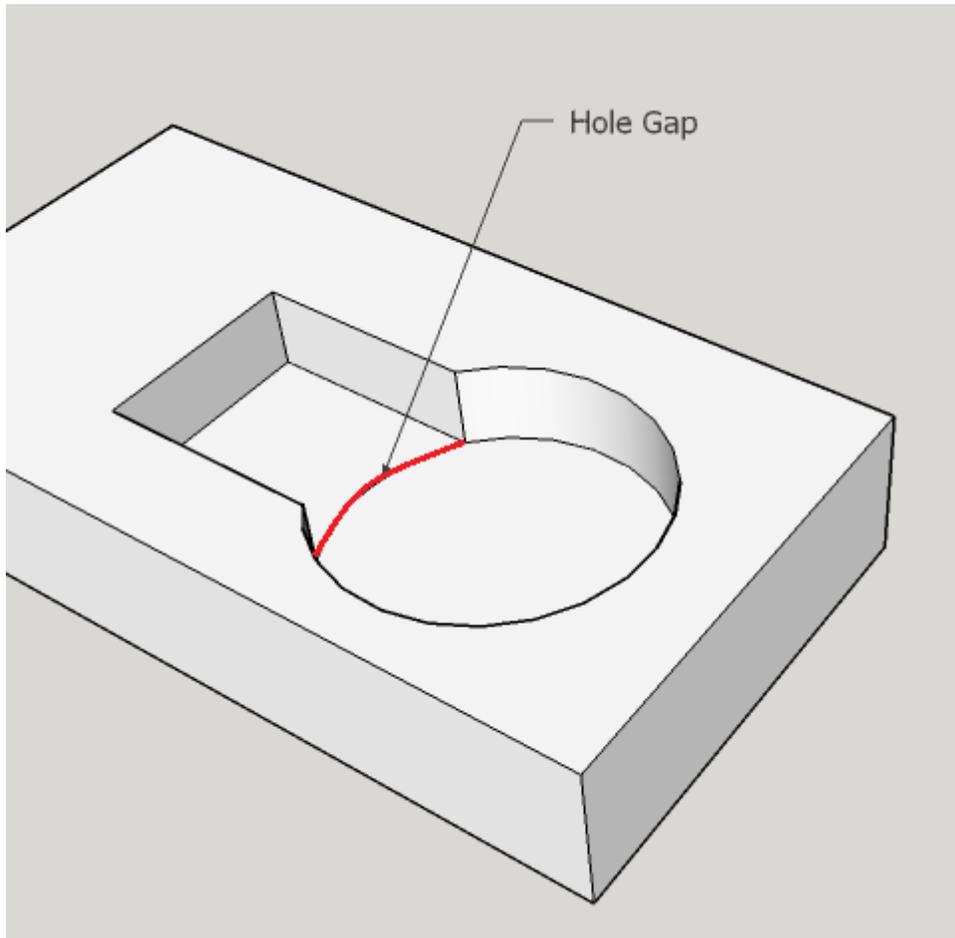
Component GCD

The Component GCD represents the whole part. Many of its important properties are listed in the *aPriori Professional User Guide*—see Component GCD in the Geometric Cost Drivers chapter.

Among the important properties are Length Direction, Width Direction, and Height Direction. Each of these is a unit vector, two of whose components are 0 (the other component is 1 or -1). These vectors can be compared with the Direction vector of another GCD (such as a Perimeter or Setup Axis) in order to determine whether the GCD's direction is aligned with the part's length, width, or height.

Hole GCD

maxHoleGap: specifies the maximum number of degrees of arc that can be missing from an extracted hole's wall. Holes with missing wall portions can sometimes be created with drilling, and so are sometimes recognized as hole GCDs. But if more than this amount is missing, no hole GCD is recognized, and a curved wall GCD is extracted instead. The default maximum hole gap is 180 degrees. In other words, if no more than half of the wall is missing, a hole GCD is recognized by default.



Parallel Surface Chain GCD

parallelSurfaceChainEnabled: set to **false** to disable extraction of parallel surface chains—see [Parallel Surface Chain](#). This is set to **true** in aPriori starting point VPEs.

Perimeter GCD

perimetersExtractionEnabled: set to **false** to disable extraction of perimeter GCDs—see [Stock Machining Routing and Plate Stock](#) and [Perimeter Milling Operation](#). This is set to **true** in aPriori starting point VPEs.

A perimeter GCD represents the boundary of the part's projection onto a plane that is orthogonal to the part's length, width, or depth direction (that is, a projection of a part along a direction parallel to the part's length, width, or height direction). For example, one perimeter of a part represents the boundary of the shadow cast by a light shining along the length of the part onto a plane orthogonal to the part's length direction.

Perimeter GCD properties include, among others, the following:

- **Direction:** this is a unit vector two of whose components are 0 (and one of whose components is 1 or -1). It can be compared with the Component GCD properties **Length Direction**, **Width Direction**, and **Height Direction** in order to determine a direction that is orthogonal to the plane containing the perimeter. For example, if a Perimeter GCD's **Direction** vector matches the Component's **Length Direction**

- vector, the perimeter is contained in a plane orthogonal to the part's length direction. (Note that two vectors match in this sense if the absolute value of each component of one vector matches the absolute value of the corresponding component of the other vector.)
- **Is Length Direction:** **true** if the perimeter is contained in a plane orthogonal to the part's length direction; **false** otherwise.
 - **Is Width Direction:** **true** if the perimeter is contained in a plane orthogonal to the part's width direction; **false** otherwise.
 - **Is Height Direction:** **true** if the perimeter is contained in a plane orthogonal to the part's length direction; **false** otherwise.

LIES_NEAR Relation

The LIES_NEAR relation is used to determine feasibility for various operations, for example, for waterjet cutting on perimeter GCDs (waterjet cutting cannot be performed on a perimeter that lies too close to a hole). Feasibility is defined in terms of the ratio of minimum wall thickness to part thickness, and minimum wall thickness is defined by the distance property of the LIES_NEAR relation between the GCD on which the operation is to be performed and the GCD closest to it.

Geometry extracts a LIES_NEAR relation for sufficiently close pairs of GCDs of the following types:

- Perimeter/perimeter pairs
- Perimeter/simple hole pairs
- Perimeter/multistep hole pairs

provided the perimeters have `isHeightDirection = true` and the holes are not blind and have axes parallel to the height direction.

With the site variables listed below, you can control what counts as sufficiently close:

- **maxRelatedDistanceMm** (6.0 in aPriori starting point VPEs)
- **maxRelatedThickness** (6.0 in aPriori starting point VPEs)
- **relatedPerimeterCoeff** (0.1 in aPriori starting point VPEs)
- **relatedPerimeterIntercept** (101.6 in aPriori starting point VPEs),
- **relatedPerimeterMaxMm** (10.0 in aPriori starting point VPEs),
- **relatedPerimeterMaxMmCutoff** (12.7 in aPriori starting point VPEs)

A perimeter/hole pair is sufficiently close if the distance between them is less than or equal to the following quantity:

GeneralDistance = max (maxRelatedThickness * Blank Thickness, maxRelatedDistanceMm)

A perimeter/perimeter pair is sufficiently close if the distance between them is less than or equal to the following quantity:

min(relatedPerimeterMaxMmCutoff, max (GeneralDistance, PerimeterLineFormula))

where

PerimeterLineFormula = relatedPerimeterMaxMm + relatedPerimeterCoeff *
 [(min (perimeter1.serLength, perimeter2.serLength)) - relatedPerimeterIntercept]

IS_ABOUT Relation

When a given a rotationally symmetric feature can potentially be machined with a given turning axis (see [Turning Axes](#)), geometry extraction creates an IS_ABOUT relation between the feature and the axis. IS_ABOUT relations are sometimes created for partially turnable features, that is, for surfaces whose finished area is greater than the sweep area.

The site variable **maxIsAboutForPlaneObstructionPercent** (5% in starting point deployment data) specifies the maximum allowable non-turnable percentage of the finished area. If more than this percent of the finished area cannot be turned using a given axis, geometry extraction does not create an IS_ABOUT relation for that surface and axis.

IS_FILLET_OF Relation

A fillet is a candidate for Indirect Filleting only if it bears the IS_FILLET_OF relation to a surface whose finishing might perform the filleting indirectly. See [Surface Milling and Turning Operations](#).

CorssSection GCD

This GCD represents the stock cross-section. Its properties include Area, Height (for rectangular stock), Outside Diameter (for round stock), Inside Diameter (for round tube stock), and Shape.

Note that the value of the Shape property is generally the same as the stock type (for example, SQUARE_BAR or ROUND_TUBE), but for plate stock (which has a rectangular cross-section) the value of the Shape property is RECTANGULAR_BAR.

Pocket GCD

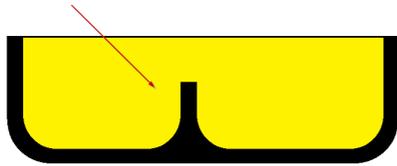
A Pocket is a volumetric GCD surrounded by walls that represents material removed by rough milling. Pocket GCDs appear in the Geometric Cost Drivers pane under the **Volume** node.

Pocket GCDs are extracted only if the site variable **pocketExtractionEnabled** is present and set to **true** (the setting in starting point VPEs). If the site variable is not present or is set to **false**, more volume will be included in a BulkRemoval GCD.

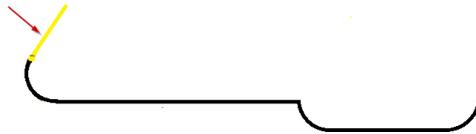
Pocket Recognition

The features recognized as pockets include

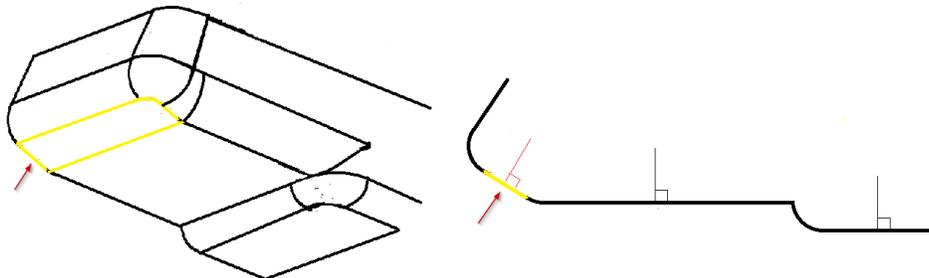
- Volume with walls and a flat floor
 - Walls can be angled with respect to the floor.
 - Walls can be with or without fillets.
 - There can be gaps in the wall provided that at least 75% of the pocket floor is closer to a wall than an opening.
- Volume with shared walls and walls that lie below other walls



- Volume with a curved floor that is sufficiently close to being flat (see below)
- Volume with walls and a cylindrical floor
- Volume with a stepped floor, provided the steps are formed only by fillets. Walls can be angled with respect to the floor

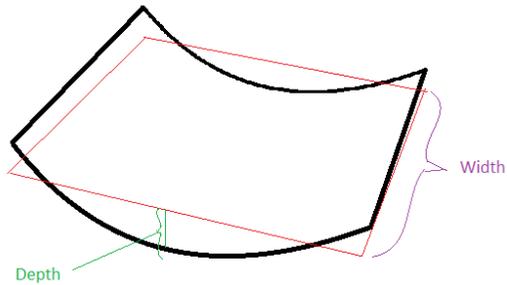


- Volume whose floor has an upward embossed feature, provided that the feature's height is one of the following:
 - Less than 20% of the height of the volume's walls (in which case the feature is assumed to have no impact on roughing tool selection).
 - More than 80% of the height of the volume's walls (in which case the geometric property **Inside Diameter** accounts for the feature, which impacts roughing tool selection).
- Volume with small, non-parallel floor segments, provided each such segment is adjacent to a perpendicular wall



- Volumes with no floor (through pockets). Walls must be parallel to one another (no + or – draft).

Curved-bottom pockets are recognized provided they are sufficiently flat. A pocket bottom is considered sufficiently flat if, roughly speaking, its depth-to-width ratio is less than the value of the site variable **maxCurvedFloorPocketWidthDepthRatio** (0.1 in starting point VPEs). Here, width is the SER width of the bottom surface, and depth is the maximum distance from the surface to its best-fit plane.



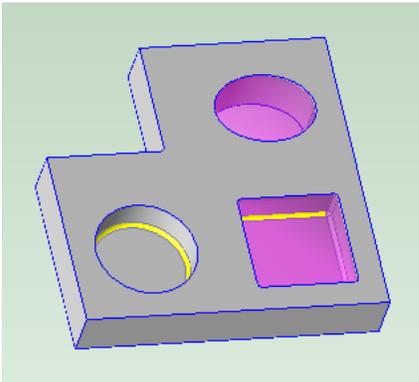
Volumes that are *not* currently recognized as pockets include:

- Open-sided volumes
- Volumes with islands
- Volumes with internal walls
- Through volumes with angled walls

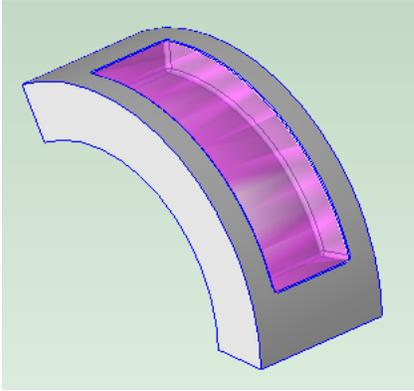
Pocket Examples

The illustration below shows three volumes:

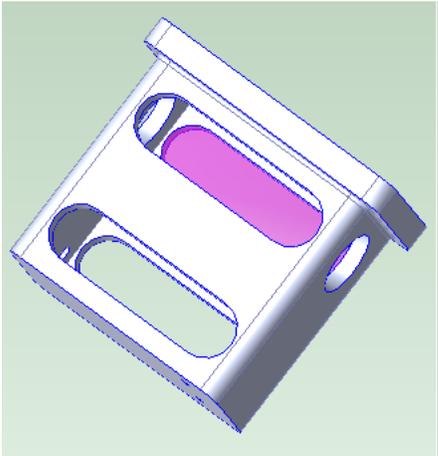
- The square volume (shown in purple) with a flat floor and fillets (one is shown in yellow) is recognized as a pocket.
- The elliptical through volume (shown in purple) is recognized as a pocket (walls of a through pocket must be parallel).
- The circular volume is *not* recognized as a pocket, but rather is identified as a simple hole.



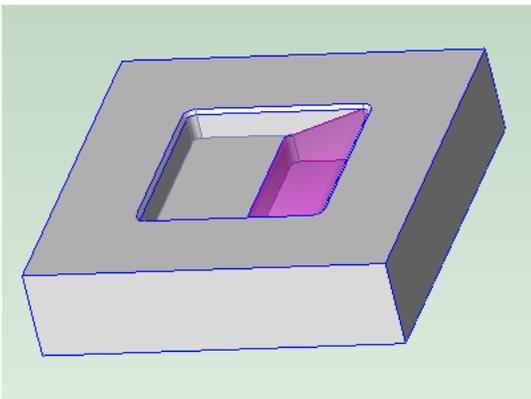
The following illustration shows a pocket (in purple) with a cylindrical floor.



The purple volume in the image below is one of four identical through pockets. The walls must be parallel for a through pocket to be recognized.



The lower volume (in purple) shown below is recognized as a pocket, while the upper volume is *not* recognized as pocket because it is open sided. These two volumes together are *not* considered a single pocket, since there would be a step in the floor that is not formed solely by a fillet.



Pocket Properties and Relations

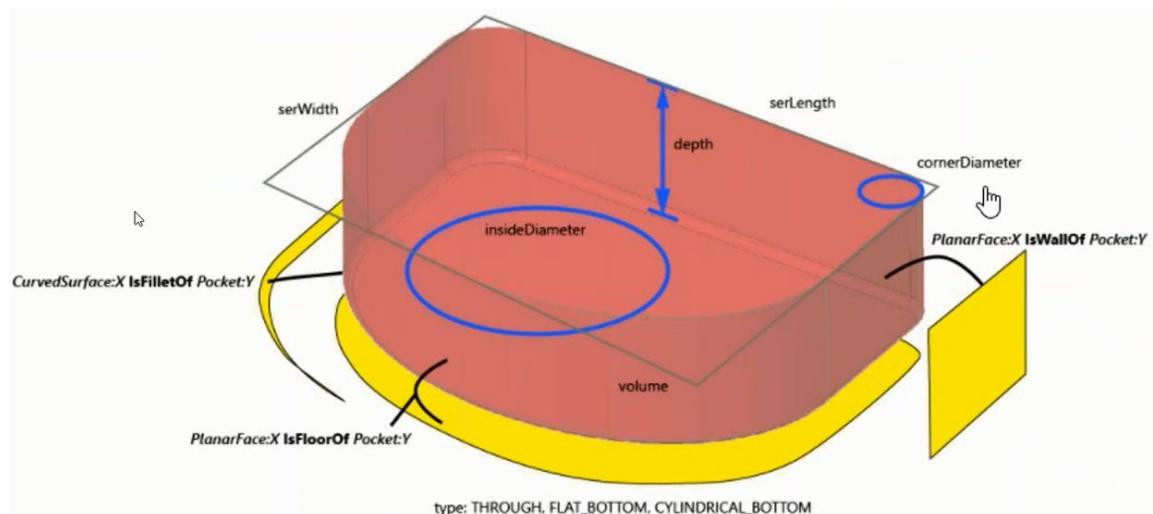
Pocket properties include the following:

- **Floor Type:** values include **THROUGH**, **FLAT**, **CYLINDRICAL**, **CURVED**, **MULTI**, and **OTHER**.

- **Wall Type:** values include **PARALLEL** and **OTHER**.
- **Direction:** specifies how direction-dependent properties (depth, corner diameter, and inside diameter tool volume) are computed. Values include **PRISMATIC**, **RADIAL**, and **OTHER**. For a **PRISMATIC** pocket, **Depth** is measured along a setup axis (either parallel to the walls or normal to the floor); for a **RADIAL** pocket, **Depth** is measured along a radius of the cylindrical floor. If the **Direction** is **Other**, **Depth** is not computed.
- **Depth**
- **Volume**
- **Corner Diameter**
- **Inside Tool Diameter:** specifies the maximum tool diameter that can access at least 80% of the pocket volume.
- **Inside Diameter Tool Volume:** specifies the volume accessed by a tool whose diameter is **Inside Tool Diameter**.

Pocket relations include the following:

- **Is Wall Of**
- **Is Floor Of**
- **Is Fillet Of**
- **Is Accessible From**



These properties and relations affect tool selection and cut time calculations—see [Diameter Selection for Pocket Roughing](#), [Tool Type Selection for Pocket Rough Milling](#), [Chipmaking Time for Pocket Rough Milling](#), and [Pocket Rough Milling Options](#).

Slot GCD

Slots are volumetric GCDs that fall into two categories:

- **Standard Slots:** generally have flat or semi-circular floors, with parallel walls normal to the floor. A standard slot can have open, cylindrical, or bathtub ends, or the slot can form a closed loop. A standard slot can also have *no* floor and parallel walls (a through slot).

- Dovetail slots: have flat floors, with symmetric, undercut walls (walls that tilt in, over the floor). Either the slot ends are both open, or the slot forms a closed loop.

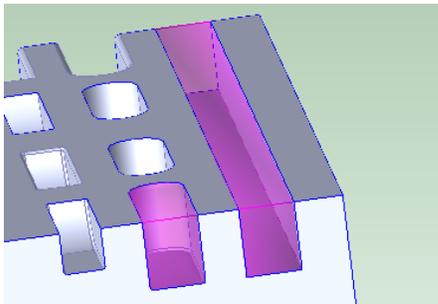
Both kinds of features are Slot GCDs; they can be distinguished from one another by their values for the property **Slot Type**.

For more information, see the following sections:

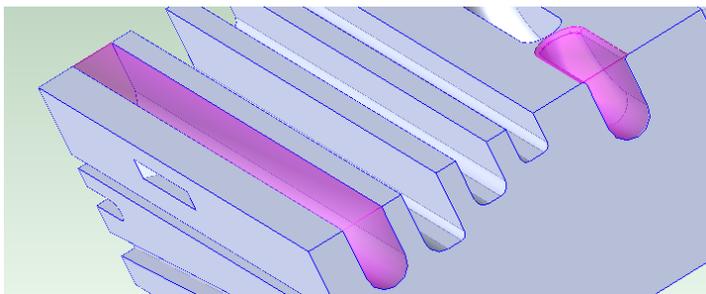
- Standard Slots
- Dovetail Slots
- Pitch and Yaw
- Slot Surfaces
- Slot Properties
- Geometries Not Recognized as Slots
- Slot Site Variables

Standard Slots

Standard slots have parallel walls. Each wall can vary in height, and the walls can be different heights from each other. Some standard slots have flat or semicircular floors, and some slots have no floor. If a slot has a floor, the walls are normal to it. The image below shows slots (in purple) with flat floors:

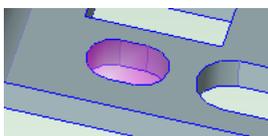


The image below shows slots (in purple) with semi-circular floors:

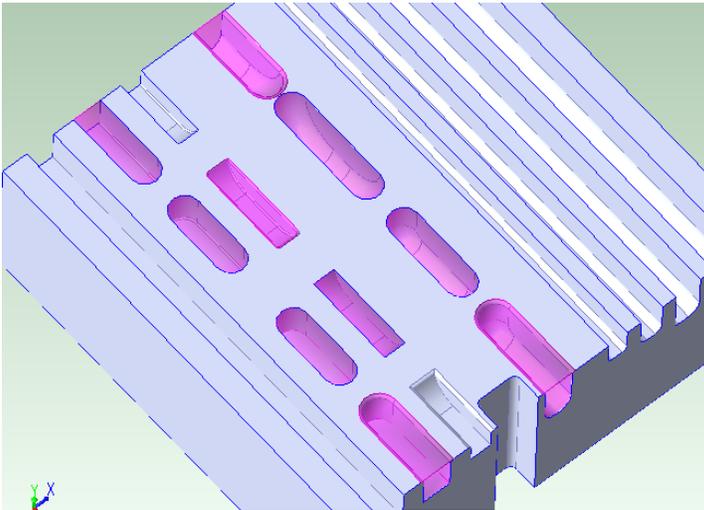


A flat floor cross-section normal to the walls and floor is a line. A semi-circular floor cross-section normal to the walls and floor is a semi-circle.

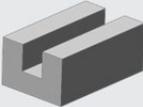
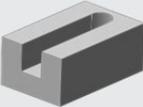
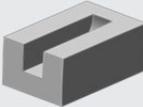
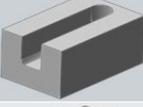
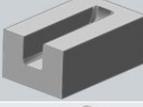
The following image shows a slot with no floor and cylindrical ends:



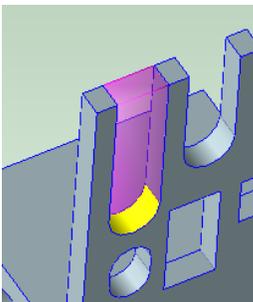
Each end of a standard slot can be open, cylindrical, or bathtub. The image below shows slots (in purple) with one or two ends:



The slots shown below are all open on one end and the other end is either open, cylindrical, or bathtub. For each, a flat floor with and without fillets is shown, as well as a semi-circular floor:

Open	Cylindrical	Bathtub
		
		
		

Sometimes, a feature that might be interpreted as a through slot with an open end is recognized as a short, deep slot, which allows for more appropriate operation assignment. The slot below (highlighted in purple) has a semi-circular floor (shown in yellow):

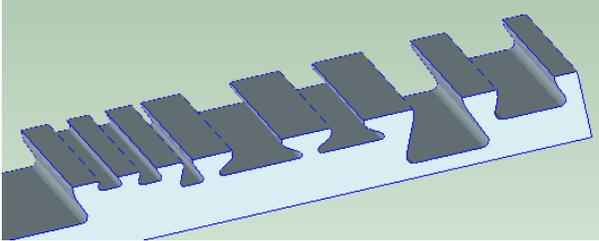


A standard slot might also form a closed loop.

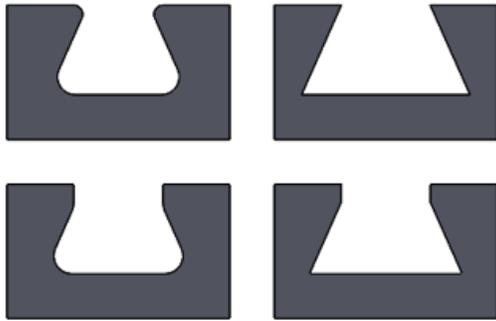
Dovetail Slots

Dovetail slots have flat floors and walls with symmetric undercuts. Each wall must be everywhere the same height. Dovetail slots are open on both ends, or else form closed loops. They are created with the help of a special finishing tool whose geometry matches the wall undercuts.

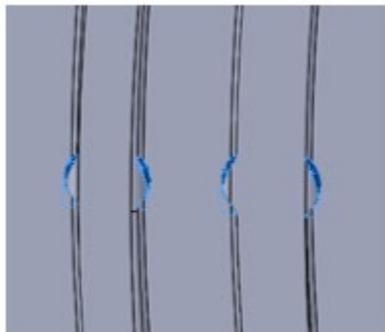
The following image shows various dovetail slots:



Dovetail slot corners can have fillets and slot walls can have rounds. A portion of the top of the walls can be normal to the floor.



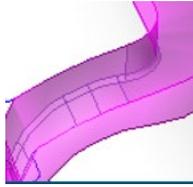
Dovetail slots can have associated drop holes, which create room for a finishing tool to be moved into position (drop holes are only recognized as such by the cost model for closed loops).



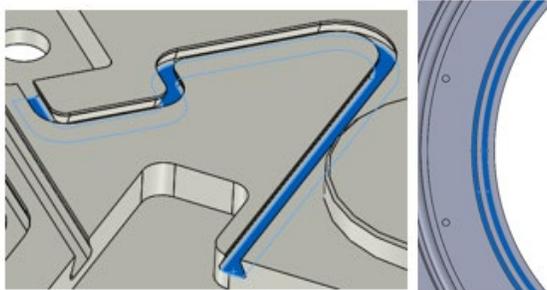
Pitch and Yaw

Standard slots can have pitch, and slots of both kinds can have yaw.

- A slot has pitch if its trajectory curves up or down at any point (that is, if the lengthwise edges of the floor do not both lie in a single plane).

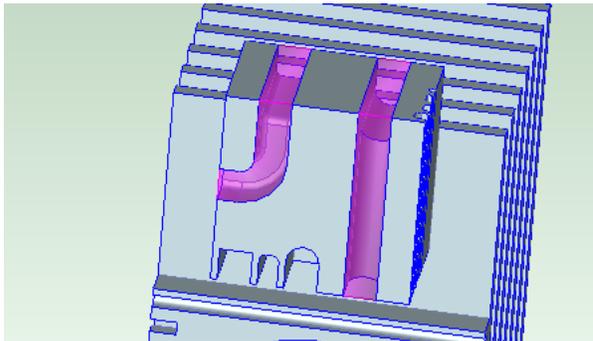


- A slot has yaw if its trajectory curves to the side at any point (that is, if each wall—or the undercut portion of each wall, for dovetail slots--does not lie in a single plane).



But note that, for a dovetail slot, any two cross-sections (in planes normal to the walls and floor) must be the same size and shape.

Note also that for a slot with pitch, the floor can be made of multiple surfaces. In the image below, the slots shown in purple pitch downward, and each has a floor composed of two different surfaces:



A through slot (one with no floor) and no yaw cannot have an open end.

Slot Surfaces

The surfaces that make up the slot floor, walls, and ends are *not* child GCDs of the Slot GCD, but they are associated with the slot through the following GCD relations:

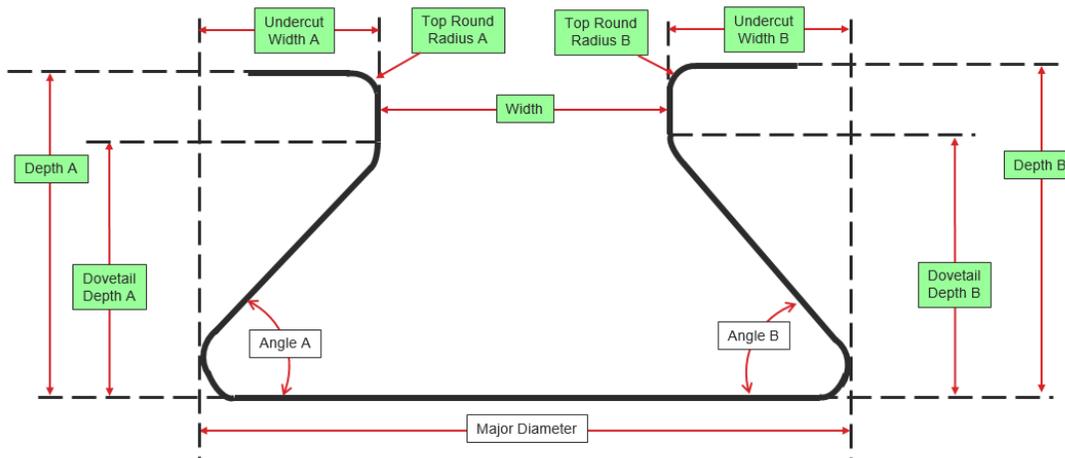
- **Is Floor Of**
- **Is Wall Of**
- **Is End Of**

Other surfaces that can be part of slot are also not child GCDs of the slot, but are related to it by the following GCD relations:

- **Is Chamfer Of**
- **Is Round Of**
- **Is Fillet Of**

Slot Properties

The following diagram shows some of the important slot properties, including some that apply only to dovetail slots:



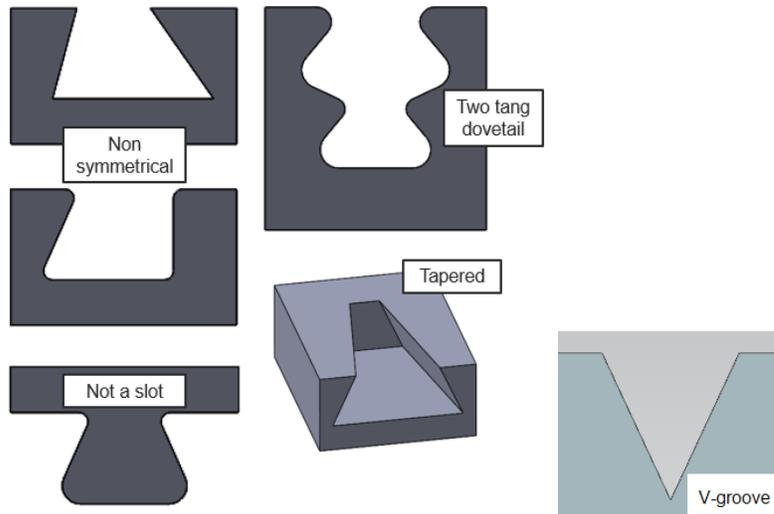
Following are the properties that appear for Slots in the Geometric Cost Drivers pane:

- **Depth A:** maximum depth of one wall. Depth is measured along a line that is normal to the floor, from the top of the wall to the floor's lowest point.
- **Depth B:** maximum depth of the other wall. Depth is measured along a line that is normal to the floor, from the top of the wall to the floor's lowest point
- **Dovetail Depth A:** for dovetail slots only. This is the depth of the undercut portions of the slot. It is measured along a line that is normal to the floor, from the top of the undercut.
- **Dovetail Depth B:** for dovetail slots only. This is the depth of the undercut portions of the slot. It is measured along a line that is normal to the floor, from the top of the undercut.
- **End1 Type:** indicates whether one slot end is **OPEN**, **BUTHTUB**, or **CYLINDRICAL**. If the slot forms a loop, this is **LOOP**.
- **End2 Type:** indicates whether the other slot end is **OPEN**, **BUTHTUB**, or **CYLINDRICAL**. If the slot forms a loop, this is **LOOP**.
- **End1 Length:** length of one bathtub or cylindrical end. This is 0 if the end is open or if the slot forms a loop.
- **End2 Length:** length of the other bathtub or cylindrical end. This is 0 if the end is open or if the slot forms a loop.
- **Has Pitch:** true if the slot trajectory curves up or down at any point (that is, if the lengthwise edges of the floor do not both lie in a single plane); false otherwise. **Has Pitch** is always false for through slots.
- **Has Yaw:** true if the slot trajectory curves to the side at any point (that is, if each wall does not lie in a single plane); false otherwise.
- **Length:** length of the slot floor, measure from one end to the other. This does *not* include the lengths of any bathtub or cylindrical ends.

- **Major Diameter:** For dovetail slots only. This is the width of the slot, including fillets (if present), measured along the floor in a plane normal to the walls and floor.
- **Min Floor Diameter:** the diameter of the tightest upward curve in the slot floor and ends. That is, the maximum tool diameter required for any bathtub end or upward pitch in the slot floor.
- **Slot Type:** For dovetail slots, the value of this property is **DOVETAIL**. For standard slots, this property indicates the slot's floor type:
 - **STRAIGHT_FLOOR** : the floor cross-section, in any plane normal to the walls, is a line.
 - **SEMICIRCULAR_FLOOR:** the floor cross-section, in any plane normal to the walls, is a semi-circle.
 - **THROUGH:** the slot has no floor. (Such a slot must *not* have an open end.)
- **Top Round Radius A:** radius of the round on the top of one wall.
- **Top Round Radius B:** radius of the round on the top of the other wall.
- **Throat Diameter:** for dovetail slots only. This is the diameter the slot's drop hole, if there is one; that is, this is the diameter of the largest circle that can fit in the drop hole opening. The value is -1 if the slot has no associated drop hole.
- **Undercut Width A:** for dovetail slots only. This is the width of the undercut portion on one side of the slot, measured along the floor in a plane normal to the walls and floor. This is the same as Undercut Width B.
- **Undercut Width B:** for dovetail slots only. This is the width of the undercut portion on the other side of the slot, measured along the floor in a plane normal to the walls and floor. This is the same as Undercut Width A.
- **Volume:** slot volume. This is the volume of material expected to be removed in order to create the slot.
- **Wall Angle A:** angle between one wall and the floor. This is 90 degrees for standard slots, and less than 90 degrees for dovetail slots. This is the same as Wall Angle B.
- **Wall Angle B:** angle between the other wall and the floor. This is 90 degrees for standard slots, and less than 90 degrees for dovetail slots. This is the same as Wall Angle A.
- **Width:** distance between the tops of the slot walls, measured in a plane normal to the walls and floor. Note that for a dovetail slot, this is different from Major Diameter, which is the width along the floor.

Geometries *Not* Recognized as Slots

Following are some examples of geometries *not* recognized as slots:



The geometry labelled **Not a slot** has volumes on either side that might be thought of as slot-like, but that do not have a parallel walls, and so are not recognized as Slot GCDs.

No through slots with two open ends are recognized. For example, no through slot connecting two through holes (whose diameters exceed the slot width) are recognized.

A volume with walls won't be recognized as a slot if the distance between the walls varies (for example, due to modelling errors).

aPiori does not recognize slots whose ends are not bathtub, cylindrical, or open. For example, aPiori does not recognize slots that end at a planar face instead of a curved wall with diameter equal to slot width; such a slot cannot be made with typical slot-making operations. In such cases, the feature may instead be recognized as a pocket, and pocket roughing settings can be adjusted to mimic a slot-making operation.

In addition, by default, the following types of volumes are not recognized as slots:

- Volumes that are too wide (compared to depth or length)
- Volumes with openings in the floor that are too large (compared to floor area)
- Volumes whose walls are very different lengths.

The thresholds that help define these types of volumes are controlled by [Slot Site Variables](#).

If a slot-like feature is not recognized as a slot because of these constraints, it might be recognized as a pocket, or included in the BulkRemoval GCD.

Slot Site Variables

This section lists several types of volumes that are *not* recognized as slots. The thresholds that help define these types of volumes are specified by site variables in the Machining process group, as described below:

- Volumes that are too wide compared to their length: a volume is considered too wide compared to its length if its width-to-length ratio exceeds the value of the site variable **slotMaxWidthToLengthRatio** (15.0 by default).

To allow recognition as slots regardless of width-to-length ratio (except for wide slots—see below), set **slotMaxWidthToLengthRatio** to -1.

- Wide, flat, open volumes that are too wide compared to their length: a volume is considered *wide* if the following holds:
 - Width exceeds the value of the site variable **wideSlotWidthMm** (50mm by default).

A *wide* volume with a flat floor that is open on both ends is considered *too wide* compared to its length if the following holds:

- Width divided by length exceeds the value of the site variable **wideSlotMaxWidthToLengthRatio** (2.0 by default).

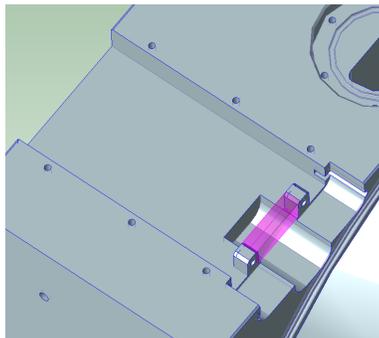
To disable this constraint on slot recognition, set **wideSlotMaxWidthToLengthRatio** to -1.

- Volumes that are too wide compared to their depth: a volume is considered too wide compared to its depth if its width-to-depth ratio exceeds the value of the site variable **slotMaxWidthToDepthRatio** (100.0 by default).

To allow recognition as slots regardless of width-to-depth ratio, set **slotMaxWidthToDepthRatio** to -1.

- Flat volumes with openings in the floor that are too large: for a volume with a flat floor and without undercut walls, the openings in the floor are considered too large if the openings' area divided by the floor's area exceeds the value of the site variable **slotMaxFloorHoleRatio** (0.8 by default).

By default, the purple volume below is not recognized as a (short, wide) slot, because it is positioned over a large floor opening.



To allow recognition as slots regardless of the ratio of opening area to floor area, set **slotMaxFloorHoleRatio** to -1.

- Volumes whose walls are very different lengths: the lengths of a volume's walls are considered too different if the ratio of the lengths exceeds the value of the site variable **slotMaxWallLengthRatio** (5.0 by default).

To allow recognition as slots regardless of wall-lengths-ratio, set **slotMaxWallLengthRatio** to -1.

If a slot-like feature is not recognized as a slot because of these constraints, it might be recognized as a pocket or included in the BulkRemoval GCD.

Routing and Feasibility for Machining

This section contains the following subsections:

- Process Routing and Feasibility

- Machine Selection
- Operation Routing and Feasibility
- Multiple Approach Surface Finishing
- Tool Selection

Process Routing and Feasibility for Machining

The automatically evaluated process routings for a fully-machined part include the following types of routings:

- 3-Axis Lathe routings
- 2-Axis Lathe and 3-Axis Mill routings
- 3-Axis Mill routings
- 5-Axis Mill routings

Below are possible routings that you must select manually:

- Mill Turn routings
- 2-Axis Lathe and 4-Axis Mill routings
- 2-Axis Lathe and 5-Axis Mill routings
- 3-Axis Mill + 5-Axis Mill routings
- 4-Axis Mill routings
- 2-Axis Bar Feed Lathe and 3-Axis Mill routings (stock machining only)
- 3-Axis Bar Feed Lathe routings (stock machining only)
- Drill Press routings (not available for stock machining)
- Jig Boring and optional Jig Grinding routing (included only if the user manually assigns a GCD to the Jig Boring operation sequence--see [Jig Boring and Jig Grinding](#).)

In each routing the main process is preceded by optional processes such as sawing, perimeter cutting, deep bore, and stock prep processes. In addition, the main process is followed by optional machining processes including Gun Drill, various Grinding processes, Automated and Manual Deburr, and Inspection processes.

Gun Drill and Grinding processes are included automatically if aPriori determines they are applicable and required to manufacture GCDs on the component (for example, if a hole is deep enough relative to its diameter to require Gun Drilling, or if surface finish requirements necessitate Grinding). Rotor Grinding also is available if helical geometry is present on the part.

For certain process groups, turning routings can include Broaching (for internal gear or keyway broaching), as well as other gear-making processes (such as Hob Machine, Shaver, and Shaper).

3-Axis Mill + 5-Axis Mill routings machine all features accessible to a 3-Axis Mill from the primary setups only, and then mill remaining unassigned features on downstream multi-axis machines. In this case, 3-Axis Mill operations include rapid rough milling of stock trim, bulk milling, perimeter milling, holemaking, facing, and easy side milling (see [Easy Side Milling Length to Diameter Ratio](#) in [Machining Node Process Setup Options](#)).

All routings have a Drill Press process which supports holmaking operations. These operations are *not* automatically assigned to holes; users can edit the operation for any hole and apply a Drill Press drilling operation.

Users also can manually include optional processes if desired, including Wire EDM and Inspection. For example, a user may wish to include optional Inspection processes to account for the time and cost of inspecting a part.

Deburring can be included, but must be manually selected. See [Routing for Deburr Processes](#).

When machining is performed following another, primary process group, a modified subset of the machining routings is available. The specific routing alternatives and processes available for secondary machining depend on the primary process group. For example, Sheet Metal routings generally include only 3-Axis Mill routings as turning routings and multi-axis routings generally don't apply to sheet metal parts. Cast parts and Forged parts include almost all categories of machining routings.

Secondary Chemical Milling can be included manually for CTL/Shear/Chemical Milling Sheet Metal routings—see [Chemical Milling](#) in the soft-tooled sheet metal chapter of this *Guide*.

These types of routings are subject to the following feasibility constraints:

- 3-Axis Lathe routings: both the following must hold:
 - Part has a turning axis and requires significant turning operations.
 - If the primary process group is Stock Machining, the stock is round.
- 2-Axis Lathe and 3-Axis Mill routings: all the following must hold:
 - Part has a turning axis and requires significant turning operations.
 - If the primary process group is Stock Machining, the stock is round.
 - No more than 4 part setup orientations are required, in starting point cost models. You can configure the maximum number of setups with the cost model variable `perpendicularCountFor3AM`. You can disable this requirement by setting the cost model variable `ruleBasedRoutingSelectionFor3AM` to `false`.
- 3-Axis Mill routings: all the following must hold:
 - Part has no AxiGroove GCD (see [Working with Gears, Splines, Sprockets, and Flutes](#)).
 - Part has no Pocket GCD that has an inward slanting wall.
 - If the primary process group is Stock Machining, the stock is not round.
 - No more than 4 part reorientations are required, in starting point cost models. You can configure the maximum number of reorientations with the cost model variable `perpendicularCountFor3AM`. You can disable this requirement by setting the cost model variable `ruleBasedRoutingSelectionFor3AM` to `false`.
- 5-Axis Mill routings: both the following must hold:
 - Part has no AxiGroove GCD (see [Working with Gears, Splines, Sprockets, and Flutes](#)).
 - If the primary process group is Stock Machining, the stock is not round.
- Mill Turn routings: both the following must hold:
 - Part has a turning axis and requires significant turning operations.
 - If the primary process group is Stock Machining, the stock is round.

- 2-Axis Lathe and 4-Axis Mill routings: all the following must hold:
 - Part has a turning axis and requires significant turning operations.
 - If the primary process group is Stock Machining, the stock is round.
 - If the cost model variable **ruleBasedRoutingSelectionForOtherRoutings** is **true** (it is **false** in starting point VPEs), the number of required part setup orientations is not excessive, The cost model variable **maxOblique4AMSetups** (0 in starting point VPEs) defines what counts as an excessive number of setups; it specifies the maximum permissible number of setups over and above the two rotational setups (see [Rotational Setup Axes](#)).
- 2-Axis Lathe and 5-Axis Mill routings: both the following must hold:
 - Part has a turning axis and requires significant turning operations.
 - If the primary process group is Stock Machining, the stock is round.
- 4-Axis Mill routings: all the following must hold:
 - Part has no AxiGroove GCD (see [Working with Gears, Splines, Sprockets, and Flutes](#)).
 - Part has no Pocket GCD that has an inward slanting wall.
 - If the primary process group is Stock Machining, the stock is not round.
 - If the cost model variable **ruleBasedRoutingSelectionForOtherRoutings** is **true** (it is **false** in starting point VPEs), the number of required part setup orientations is not excessive. The cost model variable **maxOblique4AMSetups** (0 in starting point VPEs) defines what counts as an excessive number of setups; it specifies the maximum permissible number of setups over and above the two rotational setups (see [Rotational Setup Axes](#)).
- 2-Axis Bar Feed Lathe and 3-Axis Mill routings: if the primary process group is Stock Machining, the stock must be round.
- 3-Axis Bar Feed Lathe routings: if the primary process group is Stock Machining, the stock must be round.
- Jig Boring routings: the part must have drillable GCDs. Jig Boring and Jig Grinding processes are included only if the user manually assigns a GCD to the Jig Boring operation sequence--see [Jig Boring and Jig Grinding](#).

See [Operation Routing and Feasibility](#) for information on operation feasibility.

Routing for Deburr Processes

Note: The process Debur is deprecated, and no longer appears in routings for starting point VPEs. Debur is replaced by the processes Automated Deburr and Manual Deburr. The old process, Debur, is retained for compatibility only; VPEs that use the Debur process will continue to function properly.

To apply Deburring to all (feasible) part edges, include either Manual Deburring or Automated Deburring in your routing ([Deburring Operation Feasibility](#) describes what counts as feasible). To include it, you can use a dialog accessed from either the Cost Guide or the Manufacturing Process pane.

To include deburring from the Cost Guide:

- 1 In the Production Scenario tab of the Cost Guide, click ... next to **optional process overrides**. The Include or Exclude Secondary Treatments dialog appears.

- 2 Select the Manual Deburring or Automated Deburring component-level operation.
- 3 Click **Include**.
- 4 Click **OK**.

To include deburring from Manufacturing Process pane:

- 1 In the Manufacturing Process pane, right click a node and select **Routing Selection...**. The Routing Selection dialog appears.
- 2 Navigate to the Manual Deburr or Automated Deburr process (located under Other Machining Processes).
- 3 Right click one of those processes, and select **Include** from the popup menu.
- 4 Click **OK**.

If you include deburring in this way, the GCD-level operation Automated Edge Deburring or Manual Edge Deburring is assigned to each feasible edge.

To also apply Deburring to all machined part surfaces as well as all feasible edges, use the process setup option [Include Automated Surface Deburr](#) or [Include Manual Surface Deburr](#). If you select it, Automated Surface Deburring or Manual Surface Deburring is assigned to each machined surface.

To apply Deburring to only selected individual part edges or machined surfaces, do *not* include deburring explicitly in the process-level routing. Instead, select the Edge GCD or Surface GCD of interest, right click and select Edit Operation. When the Operation Sequence Selection dialog appears, expand the Machining/Edge Treatments nodes and select the deburring operation of interest.

To apply deburring to a specified number of edges, without specifying particular edge GCDs, add to your routing the Component-level operation Virtual Automated Edge Deburring Op or Virtual Manual Edge Deburring Op, and set the Setup Option [Number of Operations](#) to a value greater than 0.

See also [Deburring Operation Feasibility](#), [Tool Type Selection for Deburring Operations](#), and [Deburring Options](#).

Machine Selection for Machining

Machine selection is described in the following sections:

- [Machine Selection for Milling and Turning](#)
- [Machine Selection for Drilling](#)
- [Machine Selection for Broaching](#)
- [Machine Selection for Jig Bore and Jig Grind](#)
- [Machine Selection for Bench Operation](#)
- [Machine Selection for Mask Spray](#)
- [Machine Selection for Mask Cure](#)
- [Machine Selection for Scribe](#)

- Machine Selection for DeMask
- Machine Selection for Etch Cell
- Determining Machine Expense

Machine Selection for Milling and Turning

In addition to actual machines, each starting point VPE provides a series of virtual machines so that you can easily compare the costs of machines of comparable capabilities. For example, you can compare the cost of machining a part on a 3-axis mill as opposed to a 5-axis mill with comparable spindle power and spindle speed.

The use of virtual machines reduces sensitivity of the aPiori results to specific machines, and helps support Design Engineering use cases such as early design cost estimation or design alternative evaluation. In practice, machining cycle times and costs are highly sensitive to the precise speed and power characteristics of the machine actually used for manufacturing.

These virtual machines:

- Provide consistent initial assumptions for machine capabilities between process routings for the purposes of initial/baseline costing.
- Minimize confounding factors to correct routing cost and cycle time directionality.
- Provide an underlying mechanism to allow for the initial preference of a particular subset of machines within a routing, in this case what we refer to as "Virtual" or generic machines.

Virtual machines are chosen by default. You can change this behavior by setting the cost model variable `preferVirtualMachines` to false.

The virtual machines and their specifications are shown in the following chart:

3 Axis Mill													
	Labor Rate (U	Direct Overh	Rapid Traverse	Spindle Power (HP)	Spindle Speed (RPM)	Travel, X	Travel, Y	Travel, Z	Table Len	Table Wid	Tool Count	Max Mill Tool Diameter (in)	
Virtual 3 Axis Mill - Small	32.42195153	35	1,500	20	10,000	23	16	17	23	16	20	4	
Virtual 3 Axis Mill - Medium	32.42195153	40	1,500	30	12,000	40	21.33	25	40	21.33	50	10	
Virtual 3 Axis Mill - Large	32.42195153	45	1,500	40	18,000	80	31.5	30.1	80	31.5	100	10	
4 Axis Mill													
	Labor Rate (U	Direct Overh	Rapid Traverse	Spindle Power (HP)	Spindle Speed (RPM)	Travel, X	Travel, Y	Travel, Z	Table Len	Table Wid	Tool Count	Max Mill Tool Diameter (in)	
Virtual 3 Axis Mill w Rotary Table - Sma	32.42195153	40	1,500	20	10,000	23	16	17	23	16	20	4	
Virtual 3 Axis Mill w Rotary Table - Med	32.42195153	50	1,500	30	12,000	40	21.33	25	40	21.33	50	10	
Virtual 3 Axis Mill w Rotary Table - Larg	32.42195153	70	1,500	40	18,000	80	31.5	30.1	80	31.5	100	10	
5 Axis Mill													
	Labor Rate (U	Direct Overh	Rapid Traverse	Spindle Power (HP)	Spindle Speed (RPM)	Travel, X	Travel, Y	Travel, Z	Table Len	Table Wid	Tool Count	Max Mill T	Max Tilt Angle (deg)
Virtual 5 Axis Mill - Small	32.42195153	50	1,500	20	10,000	23	16	17	23	16	40	3.937008	120
Virtual 5 Axis Mill - Medium	32.42195153	80	1,500	30	12,000	40	21.33	25	40	21.33	40	9.84252	120
Virtual 5 Axis Mill - Large	32.42195153	100	1,500	40	18,000	80	31.5	30.1	80	31.5	40	11.81102	120
Virtual 5 Axis Mill - Gantry	32.42195153	237.467531	1,968.50	33.52555222	20,000	1,181.10	177.165	62.9921	1,181.10	177.1654	20	11.81102	40
2 Axis Lathe													
	Labor Rate (U	Direct Overh	Rapid Traverse	Spindle Power (HP)	Spindle Speed (RPM)	Max Dia	Max Len	Max Tools					
Virtual 2 Axis Lathe - Small	32.36595507	20	900	10	5,000	12	25	10					
Virtual 2 Axis Lathe - Medium	32.36595507	25	900	35	5,000	24	50	10					
Virtual 2 Axis Lathe - Large	32.36595507	30	900	60	1,500	60	120	10					
3 Axis Lathe													
	Labor Rate (U	Direct Overh	Rapid Traverse	Spindle Power (HP)	Spindle Speed (RPM)	Max Dia	Max Len	Max Tool	Max Mill	Live Tool	Live Tooling	Spindle Speed (RPM)	
Virtual 3 Axis Lathe - Small	32.36595507	30	1,500	10	5,000	12	25	10	4	20	10,000		
Virtual 3 Axis Lathe - Medium	32.36595507	40	1,500	35	5,000	24	50	10	10	30	12,000		
Virtual 3 Axis Lathe - Large	32.36595507	50	1,500	60	1,500	60	120	10	10	40	18,000		
MillTurn													
	Labor Rate (U	Direct Overh	Rapid Traverse	Spindle Power (HP)	Spindle Speed (RPM)	Max Dia	Max Len	Max Tool	Max Mill	Live Tool	Live Tooling	Spindle Speed (RPM)	
Virtual MillTurn	32.42195153	85	1,000	35	5,000	36	160	40	10	30	12,000		

Machine selection has three distinct modes, in the following order of preference:

- 1 Select the smallest virtual machine that will fit the part if:

- Virtual machine selection is turned on in the VPE (default)
 - There is a virtual machine large enough for the part
- 2 Select the default machine specified for the process in the VPE manager if:
 - A default machine is specified
 - The machine is large enough for the part
 - 3 Select a machine as described in [Non-virtual, Non-default Machine Selection for Milling and Turning](#).

This translates into the following default behaviors:

- Virtual Machines will always be selected for the in-scope processes.
- If the VPE is configured to not allow virtual machine selection (by setting the cost model variable to **false**), the system will select the default machine -- if specified and feasible -- ahead of all other machines.
- If any machine is tagged **true** in the **Is Virtual** machine data field, it is considered within scope of virtual machine selection if turned on.
- There is intuitive and consistent cost and cycle time directionality between routings for a given part:
 - A simple, good 3-axis candidate part will naturally cost less on the 3 axis machine than the 5 axis machine.
 - Directionality remains consistent and intuitive across a range of part sizes

Non-virtual, Non-default Machine Selection for Milling and Turning

In non-virtual, non-default machine selection mode (see [Machine Selection for Milling and Turning](#)), machine selection for milling and turning picks the least expensive machine (see [Determining Machine Expense](#)) that meets all the following criteria:

- Machine is big enough to accommodate the part's dimensions (or the biggest machine, if none is big enough to accommodate the part)
- Spindle speed (the machine attribute **spindleSpeed**) is about half way between the following values:
 - Minimum spindle speed: spindle speed of the machine with the lowest spindle speed of all machines big enough to accommodate the current part's dimensions (or the spindle speed of the biggest machine, if none is big enough to accommodate the part)
 - Maximum spindle speed: spindle speed of the machine with the greatest spindle speed of all machines big enough to accommodate the current part's dimensions (or the spindle speed of the biggest machine, if none is big enough to accommodate the part)
- Spindle power (the machine attribute **power** or **spindePower**) is about half way between the following values:
 - Minimum spindle power: spindle power of the machine with the lowest spindle power of all machines big enough to accommodate the current part's dimensions (or the spindle power of the biggest machine, if none is big enough to accommodate the part)

- Maximum spindle power: spindle power of the machine with the greatest spindle power of all machines big enough to accommodate the current part's dimensions (or the spindle power of the biggest machine, if none is big enough to accommodate the part)

The selected machine's spindle speed and power are approximately as close as possible (given the available machines) to halfway between the minimum and maximum values, without falling under the halfway mark.

You can adjust how close to the maximum (relative to the minimum) the selected machine's spindle speed and power are, by specifying a value between 0 and 1 for the following cost model variables:

- **spindleSpeedBias**
- **spindlePowerBias**

These variables specify a fraction of the distance to the maximum (from the minimum). For example, 0.75 specifies three quarters of the distance from the minimum to the maximum. These variables both default to 0.5.

If routings for the parts at a plant generally have a lot of contouring, increasing **spindleSpeedBias** and **spindlePowerBias** will typically lower cycle times.

Machine Selection for Drilling

For the Deep Bore Machine process, aPriori selects the least expensive machine (see [Determining Machine Expense](#)) that meets both the following requirements

- Machine's **Max Hole Length** can accommodate the part's length (select **Component > Base Properties > Component** in the Geometric Cost Drivers pane, and see the property **length**)
- Machine's **Max Hole Diameter** can accommodate the part's width (in the Geometric Cost Drivers pane, select **Component > Base Properties > Component**, and see the property **width**).

If there is no such machine, the machine with largest **Max Table Length** is used.

For the Gun Drill process, aPriori selects the least expensive machine (see [Determining Machine Expense](#)) whose **Max Drill Length** can accommodate the part's box length (in the Geometric Cost Drivers pane, select **Component > Base Properties > Component**, and see the property **length**). If there is no such machine, the machine with largest **Max Drill Length** is used.

For the Drill Press process, aPriori selects a machine as described in [Machine Selection for Milling and Turning](#).

Machine Selection for Broaching

Broaching selects the machine with the lowest overhead (specified by the sum of the machine properties **Direct Overhead Rate** and **Indirect Overhead Rate**).

Machine Selection for Jig Bore and Jig Grind

aPriori selects only from preferred machines, if there is a feasible preferred machine and the cost model variable **usePreferredMachines** is set to **true** (the default in starting point VPEs). If there is no feasible preferred machine, or if the cost model variable

usePreferredMachines is set to **false**, aPiori selects from all machines. A machine is preferred if the machine property **isPreferred** (typically displayed as **Is Preferred**) is **true**.

CNC vs. manual machines: When aPiori selects from preferred machines, it selects only machines whose **Machine Style** property matches the value of the cost model variable **jigBoreGrindPreferredMachineStyle** (CNC in starting point VPEs).

A machine is feasible if it can accommodate the part dimensions. The largest machine is always considered feasible—the cost model assumes that the part is supported by rests in that case.

Machine Selection for Bench Operation

aPiori selects the feasible machine with the lowest overhead rate, where overhead rate is the sum of the machine properties **Direct Overhead Rate** and **Indirect Overhead Rate**. A machine is feasible if both the following hold:

- Part length is no greater than the length of the work area (specified by the machine property **Length of machine**).
- Part height is no greater than the width of the work area (specified by the machine property **Width of machine**). Note that the cost model assumes that the part is on its side during this process, with the part's height oriented along the width of the work area.

Machine Selection for Mask Spray

See [Mask Spray Machine Selection](#) in the Surface Treatment chapter of this Guide.

Machine Selection for Mask Cure

aPiori selects the feasible machine with the lowest overhead rate, where overhead rate is the sum of the machine properties **Direct Overhead Rate** and **Indirect Overhead Rate**. A machine is feasible if both the following hold:

- Machine dimensions can accommodate the part dimensions.
- If the setup option **Heated cure cycle** has been set to **false**, the Machine property **Heated Cure** is **false** (see [Mask Cure Options](#)).

The cost model assumes that the part is on its side during this process, with the part width oriented along the height of the oven. Feasibility requires that the part fit in one of the following two orientations:

- **Square fit: Part length oriented along the oven length (and the part height oriented along oven width)**
- **Diagonal fit: Part length oriented along the oven length/width diagonal**

The oven dimensions are given by the machine properties **Usable Height**, **Usable Width**, and **Usable Height**.

Machine Selection for Scribe

aPiori selects the feasible machine with the lowest overhead rate, where overhead rate is the sum of the machine properties **Direct Overhead Rate** and **Indirect Overhead Rate**. A machine is feasible if the bed dimensions can accommodate the part dimensions, that is, if all the following hold:

- Part length does not exceed the machine property **Bed Length**.

- Part width does not exceed the machine property **Bed Width**.
- Part height does not exceed the machine property **Bed Height** (the machine's Z travel)

Machine Selection for DeMask

aPriori selects the feasible machine with the lowest overhead rate, where overhead rate is the sum of the machine properties **Direct Overhead Rate** and **Indirect Overhead Rate**. A machine is feasible if both the following hold:

- Part length is no greater than the length of the work area (specified by the machine property **Length of machine**).
- Part height is no greater than the width of the work area (specified by the machine property **Width of machine**). Note that the cost model assumes that the part is on its side during this process, with the part's height oriented along the width of the work area.

Machine Selection for Etch Cell

aPriori selects the feasible machine with the lowest overhead rate, where overhead rate is the sum of the machine properties **Direct Overhead Rate** and **Indirect Overhead Rate**. A machine is feasible if the machine's tank dimensions can accommodate the part dimensions.

The cost model assumes that the part is on its side during this process, with the part width oriented along the depth of the tank. Feasibility requires that the part fit in one of the following two orientations:

- **Square fit: Part length oriented along the tank length (and the part height oriented along tank width)**
- **Diagonal fit: Part length oriented along the tank length/width diagonal**

The tank dimensions are given by the machine properties Tank Depth, Tank Length, and Tank Width. Note that these are different from the machine dimensions, which specify the footprint of the etch cell. The etch cell includes six tanks: two for rinsing and one each for etching, drying, desmut, and desmut rinse.

Determining Machine Expense

aPriori selects the least expensive machine by combining the following machine attributes:

- **Labor Rate**
- **Labor Time Standard**
- **Overhead Multiplier**
- **Overhead Rate**

These factors are combined as follows:

$\text{LaborRate} * \text{LaborTimeStandard} * (1 + \text{OverheadMultiplier}) + \text{OverheadRate}$

Operation Routing and Feasibility for Machining

This section contains the following subsections:

- Surface Milling and Turning Operations
- Hole-making and Hole-finishing Operations
- Hole Bottom Geometry and Hole Bottom Finishing
- Perimeter Milling Operation
- Threading Operations
- Edge Operations
- Keyway Broaching
- Boring Enlargement
- Back Counterboring
- Jig Boring and Jig Grinding
- Dovetail Slot Operations
- Standard Slot Operations

See also [Chemical Milling](#) in the soft-tooled sheet metal chapter of this *Guide*.

Surface Milling and Turning Operations

Each machining process generally supports a variety of individual machining operations. The operations available for the milling processes (3-Axis Mill, 4-Axis Mill, and 5-Axis Mill) can be classified into several basic groups:

- Roughing (including the bulk removal/bulk milling operation)
- Finishing
- Keyway machining
- Rounding
- Filletting
- Indirect filletting

Similarly, the turning processes (2-Axis Lathe, 3-Axis Lathe, and Mill Turn) support a wide variety of turning operations, classified into several groups including

- Rough Turning
- Finish Turning
- Back Rough Turning
- Back Finish Turning
- Grooving
- Parting

For each routing and process evaluated during costing, aPriori automatically determines which operation sequences to assign in order to manufacture each GCD on the part or assembly. Sequences are constrained by the general routing strategy that is in effect (see [General Routing Strategy](#) in [Machining Node Process Setup Options](#)).

Operation feasibility requirements for surface milling operations (on a mill machine or on a lathe with live tooling) include (but are not limited to) the following:

- Appropriate setup axis and part-relative tool orientation can be found. See [Setup Axes and Operation Feasibility](#).
- GCD has no sharp corners (corners that would require a 0 tool diameter). Consider whether you should activate a setup axis to allow facing, or (if sharp corners are not the intended geometry) modify the CAD model.
- GCD's extracted dimensions are not unreasonably small.
- For finishing operations, geometric tolerance is achievable. See the "Specifying Tolerance and Roughness" section of the *aPriori User Guide*.
- For Rounding, the GCD has a constant radius of curvature.
- For Side Milling, the selected tool has a length-to-diameter ratio that is smaller than the maximum side milling threshold. See **Maximum Side Milling Length to Diameter Ratio** in [Machining Node Process Setup Options](#).
- For Indirect Filletting, surface is a fillet that can be created by the corner radius of a bull nose end mill, as a byproduct of facing, side-milling, or flank-milling the walls adjacent to that fillet. The geometric relation **Is Fillet Of** obtains between a fillet and an adjacent wall.

In addition, the surface's fillet radius or bend diameter is sufficiently small. That is, either the fillet radius or half the bend diameter must be less than the value of the setup option **Specify Maximum Radius for Indirect Filletting** (see [Machining Node Process Setup Options](#)).

The default setting is the percentage of the part's size specified for indirect filletting in the lookup table **tblOperationSizeRanges** (12% in starting point VPEs), or else the value of the cost model variable **absoluteMaxFilletRadius** (300mm in starting point VPEs), if that's smaller.

Indirect filletting is a no-cost feature, with 0 cycle time, since it is assigned to features that are created as a side-effect of side milling, facing, or ball mill contouring.

- For Direct Filletting: surface is a fillet that must be made as a distinct operation separate from the finishing of adjacent walls. (For example, a fillet between two walls that meet at an acute angle cannot be made by indirect filletting, since the side of a standard cylindrical bull-nose end mill would interfere with one of the walls.)

Direct Filletting is assumed to use a ball nose end mill with a radius matching that of the fillet.

Direct Filletting cycle times account for the time required to drive the ball nose end mill along the fillet trajectory. Direct Filletting is much faster than Contouring, which assumes that the surface is finished with a smaller-radius ball nose end mill and must traverse multiple back-and-forth toolpaths in order to "scrub" the surface.

See also [Multiple Approach Surface Finishing](#).

Operation feasibility requirements for surface turning operations include the following:

- An appropriate turning axis is available.
- For internal GCDs, boring bar length to diameter ratio is within range.
- For finish turning and back finish turning, geometric tolerance is achievable.

- For grooving, there is face and radial tool accessibility.

Hole-making and Hole-finishing Operations

The machining cost model supports the following hole-making operations:

- Step Drilling (must be manually selected)
- Counterboring
- Center Drilling
- Drilling
- Pecking
- Groove Turning
- Groove Milling
- Gun Drilling
- Preturn Drilling
- Postdrill Rough Turning
- Rough Boring
- Semi-finish Boring (see [Boring Enlargement](#))
- Jig Boring (See [Jig Boring and Jig Grinding](#))
- Large Hole Milling (Rough Milling followed by Side Milling)
- Large Hole Turning (Preturn Drilling followed by Postdrill Rough Turning)

The machining cost model supports the following hole-finishing operations:

- Reaming
- Finish Turning
- Finish Boring
- Jig Grinding operations (General Grinding, ID Finish Plunge Grinding, ID Finish Traverse Grinding)

See also [Threading Operations](#) and [Edge Operations](#).

All hole-making operations are subject to the following constraints:

- GCD is not flanged.
- GCD is not obscured (undercut)—except for Groove Milling and Turning operations.
- Appropriate setup axis exists--except for Back Counterboring. See [Setup Axes and Operation Feasibility](#).

Below are additional feasibility constraints, listed by operation. Note that, for each process, acceptable ranges (such as diameter ranges and length-to-diameter ratio ranges) are specified in the lookup table **tblOperationSizeRanges**.

Deep Bore Machine operations:

- Drilling and Trepanning
 - GCD axis is coincident with part's turning axis.

- GCD diameter is within range.
- GCD length-to-diameter ratio is within range.

Gun Drill operation:

- Drilling
 - GCD length-to-diameter ratio is within range.
 - Required tolerance is achievable by the operation.

Drill Press, Mill, and Lathe operations:

- Boring
 - GCD diameter is within range.
 - Required tolerance is achievable by the operation.
- Center Drilling:
 - GCD length-to-diameter ratio is within range.
 - GCD diameter is within range, if the part is delicate (see the cost model variable **delicatePartRatio**).

Note that optionality rules remove center drilling from an operation sequence if the GCD's axis coincides with the stock's axis, for tube stock.

Similarly, center drilling is removed from an operation sequence if the GCD is part of a multistep hole but is not the smallest hole of the multistep hole.

- Countersinking
 - GCD has a chamfered edge.
 - GCD diameter is within range.

Note that, when a hole is countersunk at both ends, a current limitation in geometry extraction prevents the cost model from assigning distinct setup axes to each countersinking operation. While the cost model accounts for the cost of both countersinking operations, it only accounts for the cost of the setup for one of the operations.

- Drilling
 - GCD length-to-diameter ratio is within range.
 - GCD is part of a multistep hole only if it is the smallest hole of the multistep hole.
- Counterboring
 - GCD is part of a multistep hole and is *not* the smallest hole of the multistep hole.
 - GCD diameter is within range.
- Back Counterboring; see [Back Counterboring](#).
- Pecking
 - GCD length-to-diameter ratio is within range.
 - GCD diameter is within range, if the part is delicate (see the cost model variable **delicatePartRatio**).
- Reaming
 - GCD diameter is within range.

- Required tolerance is achievable by the operation.

Other Mill and Lathe operations:

- Finish Turning
 - GCD length-to-diameter ratio is within range.
 - Required tolerance is achievable by the operation.
- Finish Boring
 - GCD diameter is within range.
 - Required tolerance is achievable by the operation.
- Postdrill Rough Turning
 - GCD's axis is coincident with part's turning axis.
 - GCD diameter is within range.
 - GCD length-to-diameter ratio is within range.
- Preturn Drilling
 - Part is not made from tube stock
 - GCD is part of a multistep hole only if it is the smallest hole.
- Rough turning
 - GCD length-to-diameter ratio is within range.
- Gun Drilling
 - Machine supports gun drilling (as specified by the machine property **Can Gun Drill**).
 - GCD length is less than the value of the cost model variable **maxGunDrillingLegth**.
 - GCD length-to-diameter ratio is within range.
 - Required tolerance is achievable by the operation.
- Side Milling
 - GCD length-to-diameter ratio is within range.
 - Required tolerance is achievable by the operation.
- Hole Bottom Finishing (see [Hole Bottom Geometry and Hole Bottom Finishing](#))

Hole Bottom Geometry and Hole Bottom Finishing

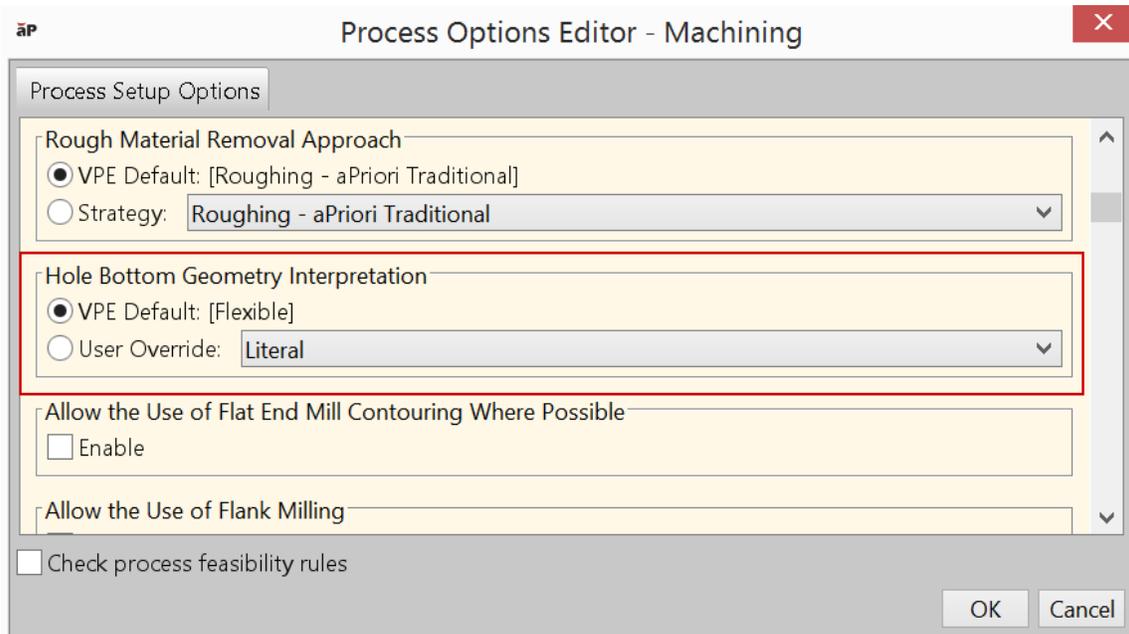
By default in starting point VPEs, the cost model does not take CAD-modeled hole bottom geometry literally; it assumes that hole bottoms are conical in shape, regardless of how they are modelled in CAD. That is, by default in starting point VPEs, the cost model assumes that the actual hole bottom is produced by the tip of a standard drilling tool, and that no milling operations are required to achieve the desired shape.

VPE administrators can customize this default with the cost model variable **flatHoleBottoms**. The cost model variable has two possible values:

- **Flexible:** This is the default. Hole bottoms are *not* interpreted literally. Milling operations are *not* assigned to the hole-bottom surfaces; the hole is assumed to be made by a drilling sequence alone (unless the diameter of the hole is beyond the drillable diameter threshold and the hole is routed to a rough/finish milling operation sequence).

- **Literal:** Hole bottoms are interpreted literally. Milling operations are assigned to the hole-bottom surfaces, if necessary.

Users can override the default behavior on a part-by-part basis with the setup option **Hole Bottom Geometry Interpretation**, defined on the **Machining** routing node.

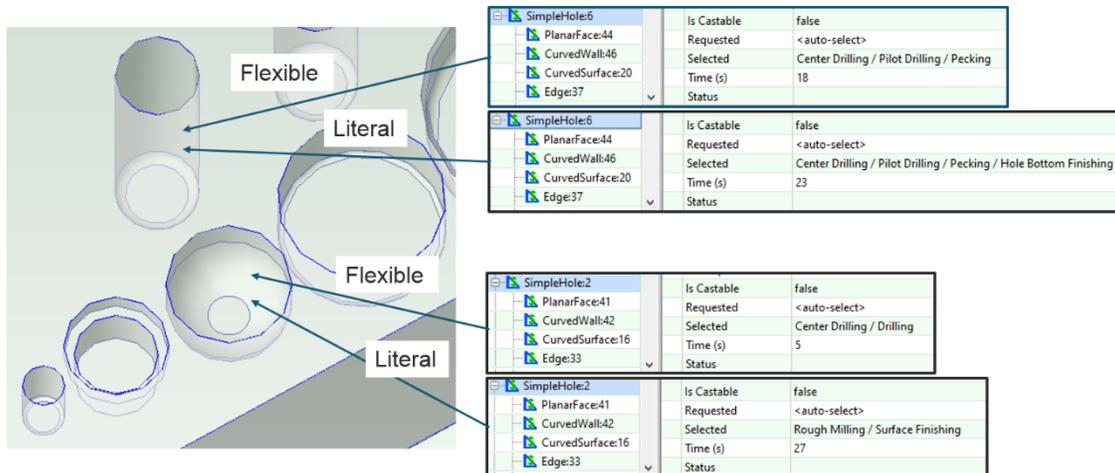


The setup option has two possible settings (with the same meanings as the associated cost model variable values):

- **Flexible:** This is the default. Hole bottoms are *not* interpreted literally. Milling operations are *not* assigned to the hole-bottom surfaces. The hole is assumed to be made by a drilling sequence alone.
- **Literal:** Hole bottoms are interpreted literally. Milling operations are assigned to the hole-bottom surfaces, if necessary.

To override the default for a particular hole, manually assign a specific hole-making operation sequence to the hole, or assign surface-finishing operations to the hole's child surfaces.

The example below shows the costing results of both the flexible and literal interpretations of two different holes.



The first hole is modeled in CAD with a flat bottom. With the **Flexible** setting, the flat bottom is assumed to be a modeling simplification, and is not interpreted literally; the hole is assumed to be created by the drilling sequence **Center Drilling > Pecking** alone. No finishing operations are assigned, resulting in a shorter cycle time, compared to the results of the **Literal** setting.

With the **Literal** setting, the first hole is assigned finishing operations subsequent to the drilling sequence:

- Planar Face facing
- Curved Surface filleting

resulting in a longer cycle time, compared to the results of the **Flexible** setting.

The second hole is modeled in CAD with a nearly spherical bottom. With the **Flexible** setting, the modeled hole bottom geometry is not interpreted literally; the hole is assumed to be created by the drilling sequence **Center Drilling > Drilling** alone. No finishing operations are assigned, resulting in a shorter cycle time, compared to the results of the **Literal** setting.

With the **Literal** setting, the second hole is roughed and finished with milling operations. Finishing operations include:

- Planar Face facing
- Curved Wall side milling
- Curved Surface indirect (no cost) filleting (a secondary effect of Curved Wall side milling)

resulting in a longer cycle time, compared to the results of the **Flexible** setting.

Perimeter Milling Operation

The 3 Axis Mill, 4 Axis Mill, and 5 Axis Mill processes provide the Perimeter Milling operation. Perimeter milling is a technique used to mill external or internal contours of through-all features, resulting in a “dropped-off” volume of material either outside or inside the milled perimeter. Without the use of perimeter milling, all removed starting billet volume is converted to chips.

With Stock Machining, aPriori decides to include Perimeter Milling in a perimeter GCD’s operation sequence if all the following hold:

- Setup option **Roughing Technique** is set to **Perimeter Milling with Dropoff**. The default setting is specified by the Stock Machining cost model variable **defaultRoughingTechnique** (**All Bulk Milling** in starting point VPEs--see [Stock Machining Node Process Setup Option](#)).
- Perimeter is external (see [PSCs and Perimeters](#)).
- Perimeter is sufficiently closely aligned with a principal, rotational, or user-activated setup axis. Maximum allowable misalignment is specified by the Machining cost model variable **perimeterMillingAngularTolerance** (5 degrees in starting point VPEs).

You can turn perimeter milling on or off for individual Perimeter GCDs by editing the GCD's operation sequence.

See also [Stock Machining Routing and Plate Stock](#).

Threading Operations

All threading operations are subject to the following feasibility constraints:

- GCD is threaded.
- GCD diameter is within range (as specified in the lookup table **tblOperationSizeRanges**).
- Current operation sequence does not contain a prior threading operation.
- Material is compatible with threading (based on cut code) on the current machine.

Edge Operations

Edge treatment operations are subject to the following feasibility constraints:

- Chamfer milling and Countersinking:
 - Edge is chamfered.
 - Diameter is within range (as specified in the lookup table **tblOperationSizeRanges**).
- Countersinking:
 - Edge is chamfered.
 - Diameter is within range (as specified in the lookup table **tblOperationSizeRanges**).
- Round milling:
 - Edge is rounded.
- Edge turning:
 - Appropriate turning axis exists.
 - Edge is not sharp.

Keyway Broaching

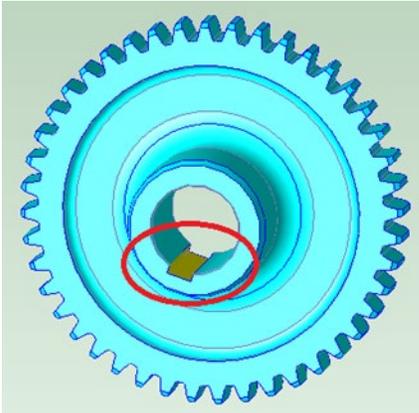
Keyway broaching operations include the following:

- Single Pass Keyway Broaching. This used by default. It is pull-type keyway broaching, suitable for high-volumes.

- Multipass Keyway Broaching. This must be selected manually. It is shim-type keyway broaching, suitable for low volumes.

The feasibility rules for these operations require that the keyway GCD have the following characteristics:

- Bottom is flat.
- Open at both ends (through).
- No shoulders obstructing line of sight.
- Internal.
- Desired tolerance is achievable by the operation.



Internal Keyway appropriate for Broaching

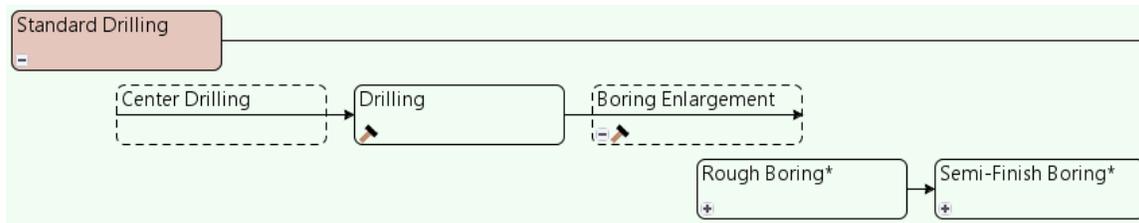
Note that only keyways with rectangular cross-sections are recognized by geometry extraction.

Boring Enlargement

Hole that are around 1 to 2 inches in diameter and that have tight positional or diametrical tolerance may be assigned an operation sequence that includes boring enlargement (rough boring followed by semi-finish boring).

Optional boring enlargement is available as part of the Standard Drilling operation and Drilling and Boring sequences. A hole that meets *all* the following conditions is assigned a Standard Drilling operation sequence:

- Hole is not undercut.
- Diameter is within range for Standard Drilling, as specified by the lookup table **tblOperationSizeRanges**. In starting point VPEs, this is less than 20% of the part's length, width, or height, whichever dimension is between the other two.
- *At least one* of the following holds:
 - Length-to-diameter ratio is within range for Standard Drilling (as specified by the lookup table **tblOperationSizeRanges**)—less than 3 in starting point VPEs). Deep drilling and gun drill are not supported.
 - Part is not delicate (that is, the ratio of the part's two smallest box dimensions is less than the cost model variable **delicatePartRatio**—8 in starting point VPEs).
 - Hole requires boring enlargement (see below).



Boring enlargement is required for a hole, and included in the Standard Drilling sequence, if the hole meets *all* the following conditions:

- Diameter falls between the following two values (inclusive):
 - Cost model variable **roughBoringLowerDiameter** (25.4mm in starting point VPEs)
 - Cost model variable **roughBoringUpperDiameter** (50.8mm in starting point VPEs)
- *At least one* of the following holds:
 - Positional tolerance is less than the value of the cost model variable **roughBoringToleranceThreshold** (0.254mm in starting point VPEs).
 - Diametrical tolerance is less than the value of the cost model variable **roughBoringToleranceThreshold** (0.254mm in starting point VPEs).
- Bottom is not flat (that is, the hole bottom is *not* a PlanarFace).
- Tools of the required sizes can be found (as specified by the lookup table **tblSystemToolDeclarations**)

Boring enlargement consists of *both* the following operations:

- Rough Boring
- Semi-Finish Boring

Note that boring enlargement (Rough Boring followed by Semi-Finish Boring) is followed by Finish Boring, if a finishing step is necessary to achieve the required tolerance. The operations in this sequence are assumed to use the following types of tools:

- Rough Boring: 3-tooth mill bore
- Semi-Finish Boring: 2-tooth mill bore
- Finish Boring: 1-tooth mill bore

Note: *Do not specify Number of Occurrences for Rough Boring or Semi-Finish Boring.* Use the setup options listed below, instead.

You can control the number of passes performed by each operation with the following setup options:

- **Num Semi Finish Boring Passes:** In starting point VPEs, the default number of semi-finishing passes is 2. You can customize the default number of passes with the cost model variable **defaultNumSemiFinishBoringPasses**. You can override the default on a GCD-by-GCD basis with this setup option; specify a value greater than or equal to 1.
- **Number of Rough Boring Passes:** By default, aPriori determines the number of rough boring passes based on the following factors:

- Hole radius: This is the depth of material (measured from the center outwards) that must be removed in order to create the hole.
- Radius of the initial drilling pass: this is the depth of material removed by the Drilling operation, that is, half the diameter of the Drilling tool. In starting point VPEs, the drill diameter for this initial operation of the sequence is 70% of the hole diameter (or the maximum available drill size, whichever is smaller). VPE administrators can customize this percentage with the cost model variable **enlargementDrillAsFractOfHole**.
- Number of semi-finishing passes (see above)
- Depth of a single semi-finishing pass: This is either 7.2mm or half the depth not removed by initial drilling and finishing, whichever is less.
- Whether a finishing pass is required and, if so, its depth (that is, the depth of material removed by the hole finishing operation). If a finishing pass is required, this is assumed to be 0.3% of the hole radius, provided this value falls between 0.0508mm (0.002 inches) and 0.127 (0.005 inches).
- Depth of a single, typical rough boring pass. This is assumed to be 7.5mm.

aPiori uses this information to determine the depth of material that must be removed by rough boring in order that the total depth of material removed by all operations adds up to the hole radius. The required number of passes is the depth that must be removed by rough boring divided by the depth of a single typical rough boring pass, rounded up to the nearest whole number of passes.

You can override the default on a GCD-by-GCD basis with this setup option; specify a value greater than or equal to 1.

Note that boring of cast holes is not currently supported.

Boring data such as feed and speed data are stored in the lookup table **tblBoringV2**; the lookup table **tblBoring** is retained for compatibility only.

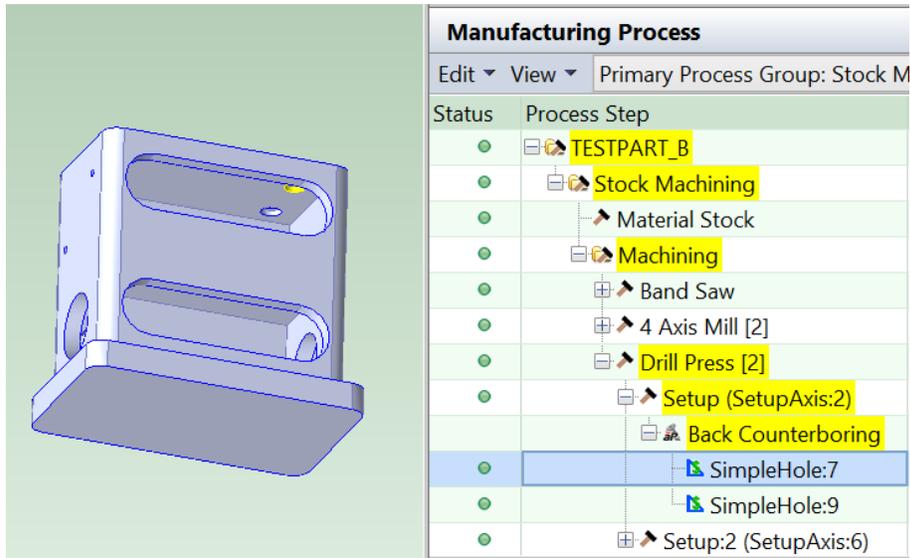
Back Counterboring

For 3-Axis Mill, 4-Axis Mill, 5-Axis Mill, Mill Turn, and 3-Axis Lathe routings, inaccessible counterbores are assigned to the Back Counterboring operation performed by the Drill Press process. Back counterboring is assigned to a simple hole that meets the following conditions:

- Is a child of a multistep hole
- Is not the smallest-diameter child of that multistep hole
- Is not accessible from any setup axis

In this case, the cost model assumes that the hole is created using a manually-assembled, multi-piece counterboring tool. (Note that such a tool is *not* a tool with an expandable cutting edge that can be collapsed, fed through the smaller diameter, and then expanded.)

The hole shown in yellow, below, is assigned to back counterboring:



Backboring cycle time includes time to do all the following

- Feed the main tool piece through the smaller-diameter hole, and attach the back counterboring tool piece to the main tool piece.
- Center the drill press.
- Cut the hole (see [Cut Time for Machining Operations](#)).
- Detach the back counterboring tool, and remove the main piece.

Time to assemble and disassemble the tool is specified by the cost model variable **counterBoringToolChangeTime** (1 minute in starting point VPEs). Time to center the tool is specified by the cost model variable **drillPressToolCenterTime** (10 seconds in starting point VPEs).

Jig Boring and Jig Grinding

Jig Boring and Jig Grinding processes are included only if the user manually assigns a GCD to the Jig Boring operation sequence (which includes Jig Grinding for GCDs with tight tolerances).

This operation sequence is available for parts manufactured with the following primary process groups:

- Stock Machining
- 2-Model Machining
- Casting (Die and Sand)
- Forging

The Jig Boring operation is feasible for a GCD only if all the following hold:

- Part is not delicate or diameter is sufficiently small (as specified in **tblSystemToolDeclarations**).
- GCD's length-to-diameter ratio within range.
- GCD is not undercut.

A GCD that has been assigned to jig boring will be assigned to jig grinding if the upstream operations can't achieve the required positional tolerance, diametrical tolerance, or roughness.

Jig grinding is feasible only on materials with compatible cut codes (41,42, 51, or 52).

Note the following about costs associated with jig boring and jig grinding:

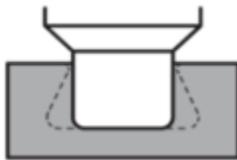
- They occur on separate Jig Boring machines and Jig Grinding machines, and so they incur batch setup costs, as well as part setup costs.
- Part setup times based on positional tolerance. The time is based on linear interpolation:
 - For Jig Boring, it falls somewhere between the values of the cost model variables **jigBoreMinPartSetupTime** (2 hours in starting point VPEs) and **jigBoreMaxPartSetupTime** (6 hours in starting point VPEs), depending on where part's tightest required tolerance falls between the cost model variables **jigBoreMinPosTol** (0.005mm in starting point VPEs) and **jigBoreMaxPosTol** (0.0254mm in starting point VPEs).
 - For Jig Grinding, it falls somewhere between the values of the cost model variables **jigGrindMinPartSetupTime** (2 hours in starting point VPEs) and **jigGrindMaxPartSetupTime** (6 hours in starting point VPEs), depending on where part's tightest required tolerance falls between the cost model variables **jigGrindMinPosTol** (0.005mm in starting point VPEs) and **jigGrindMaxPosTol** (0.0254mm in starting point VPEs).
- Tool indexing costs are much higher for non-CNC machines (see [Machine Selection for Jig Bore and Jig Grind](#)).

Dovetail Slot Operations

Dovetail slots are Slot GCDs whose **Slot Type** property is set to DOVETAIL (see [Slot GCD](#)). These slots have flat floors and symmetric, undercut walls. They are open on both ends. Any two cross-sections (in planes normal to the walls) are the same size and shape. Dovetail slots are created with the help of a special finishing tool whose geometry matches the wall undercuts.

The operation sequence for dovetail slots always includes a roughing operation followed by a finishing operation, and is sometimes followed by a rounding operation:

- **Roughing operation:** dovetail slot roughing uses a flat end mill to remove all the material necessary to create the slot *except* for the slot's undercuts. So the roughed out portion of the slot has parallel walls.

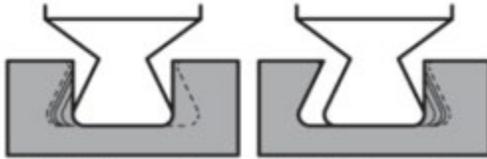


The roughing operation is one of the following:

- Slot Milling: this is used if an appropriate tool can be found. See [Diameter Selection for Slot Milling](#).
- Rough Milling: this is used if *no* appropriate slot milling tools can be found and an appropriate rough milling tool *can* be found. See [Diameter Selection for Slot Rough Milling](#).

See [Standard Slot Operations](#) for more information on Slot Milling and Rough Milling.

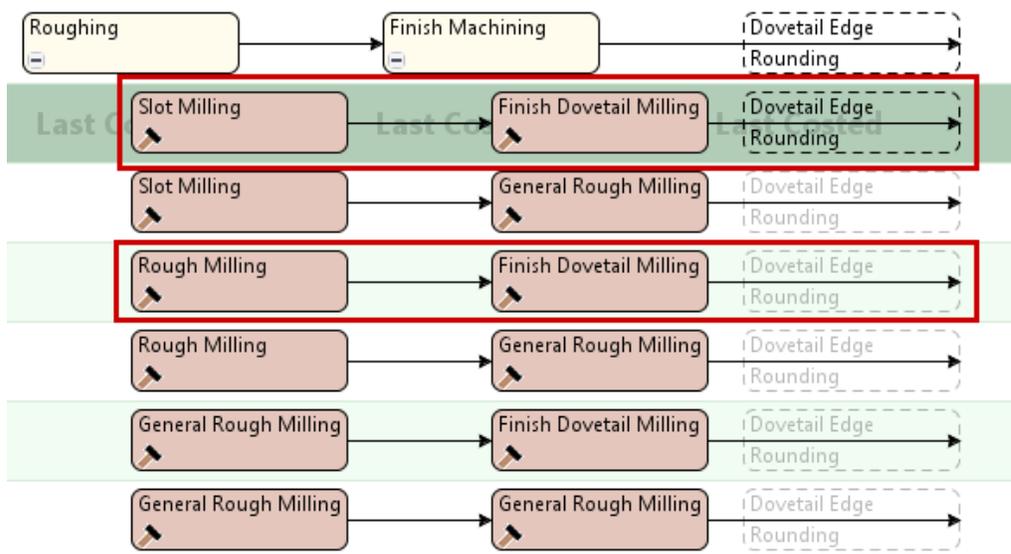
- **Finish Dovetail Milling:** dovetail finishing uses a tool whose geometry matches the angle of the slot walls. In two or more passes per side, the tool removes the material that occupies the undercut portions of the slot.



- **Dovetail Edge Rounding:** this operation is included in the operation sequence if and only if both the following hold:
 - Slot has rounded edges.
 - Slot is a closed loop with no modeled drop hole.

For open-ended dovetails and loops with drop holes, the cost model assumes that rounding is performed by Finish Dovetail Milling, whose tool geometry is assumed to accommodate the rounds.

Note that if you specify the presence of a drop hole with the setup option **Drop Hole Override** (see [Dovetail Finishing Options](#)), but no drop hole is modeled in the CAD, rounding is nevertheless applied when the slot has rounds.



Slots for which no appropriate Slot Milling or Rough Milling setup or tool can be found (see [Standard Slot Operations](#)) are assigned General Rough Milling. Similarly, slots for which no appropriate Finish Dovetail Milling setup or tool can be found (see [Diameter Selection for Dovetail Slot Finishing](#)), are assigned General Finish Dovetail Milling. These are fallback versions of Rough Milling and Dovetail Finish Milling that use a much smaller tool diameter.

For all operations, the tool axis is normal to the slot floor.

Some of the terms used above can be defined in terms of GCD properties and relations as follows:

- *Slot is a dovetail slot:* the geometric property **Slot Type** has value **DOVETAIL**.

- *Slot has rounded edges*: the geometric property **Top Round Radius A** or **Top Round Radius B** is greater than 0.
- *Slot is a closed loop*: the geometric properties **End1 Type** and **End2 Type** have value **LOOP**.
- *Slot has no modeled drop hole*: a loop without a drop hole has a value of -1 for the property **Throat Diameter** (the diameter of the drop hole).

See also [Slot Properties](#).

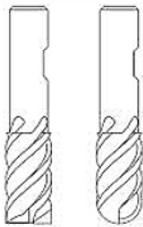
Standard Slot Operations

This section covers the operations used to make standard slots. Some of these operations are also used to help create dovetail slots (see [Dovetail Slot Operations](#)).

Standard slots are Slot GCDs that are *not* dovetail slots. For these slots, the **Slot Type** property is not **DOVETAIL**, but rather indicates the slot's floor type: **STRAIGHT_FLOOR** (for a flat floor), **SEMICIRCULAR_FLOOR**, or **THROUGH** (for no floor). Standard slots have parallel walls that are normal to the floor, and they can have open, cylindrical or bathtub ends. They can also form a closed loop. See Slot GCD.

Standard slot roughing is performed by one of the following operations:

- **Slot Milling**: this operation uses a flat end mill or a ball end mill (see [Tool Type Selection for Standard Slot Milling](#)) whose diameter is the width of the slot (see [Diameter Selection for Slot Milling](#)). It creates the slot in one or more axial passes, with full radial engagement along the width of the slot, and an axial depth of cut of half the tool diameter (by default).

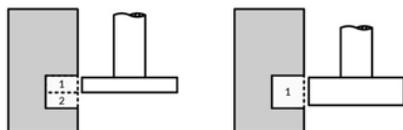


There are two preferred tool axis orientations for this operation:

- Normal to the slot floor: during each pass, the tool moves along the *length* of the slot, with an axial depth of cut that runs along the *depth* of the slot.
- Parallel to the slot floor and walls: during each pass, the tool moves along the *depth* of the slot, with an axial depth of cut that runs along the *length* of the slot.

In some cases, the operation is performed with a ball end mill oblique to the floor.

- **Groove Milling**: this operation uses a wheel cutter (a groove mill or a keyseat mill), and orients the tool axis normal the slot walls. The tool width is less than or equal to the slot width (see [Tool Width Selection for Groove Milling](#)).



Groove Milling creates the slot in one or more axial passes and one or more radial passes. During each pass, the tool moves along the length of the slot, with full axial engagement (along the width of the tool and width of the slot), and a radial depth of cut, along the depth of the slot, that is 50% of the tool width.

Unlike Slot Milling on a 3-Axis Mill, this operation is feasible for flat-floor slots with upward pitch or bathtub ends. It can also make some slots that are obstructed from the tool approaches used by Slot Milling.

- **Rough Milling:** as with Slot Milling, this operation uses a flat end mill or a ball end mill (see [Tool Type Selection for Standard Slot Milling](#)). Unlike Slot Milling, Rough Milling can use a tool whose diameter that is less than the width of the slot (see [Diameter Selection for Slot Rough Milling](#)), so it is appropriate for slots that are too wide for Slot Milling. It creates the slot in multiple radial and axial passes. As with Slot Milling, there are two preferred tool axis orientations: normal to the slot floor, and parallel to the slot floor and walls. In some cases the operation is performed with the a ball end mill oblique to the floor.
- **General Rough Milling:** a version of Rough Milling that uses a 20% lower feed, this provides a fallback when no other milling operation is feasible with an appropriate tool and setup.
- **Wire EDM:** must be manually assigned.

Finishing of standard slots is performed on the individual surfaces of the slot. Note that the surfaces that make up the slot floor, walls, ends, fillets, rounds, and chamfers are *not* child GCDs of the Slot GCD, but they are associated with the slot through GCD relations: **Is Floor Of**, **Is Wall Of**, and **Is End Of**, **Is Fillet Of**, **Is Round Of**, and **Is Chamfer Of**.

If more than one of the above operations is feasible for a slot, Slot Milling is generally preferred, followed by Groove Milling and Rough Milling. General Rough Milling is used only if the other three cannot be assigned. Wire EDM must be manually assigned.

Operation assignment depends both on the feasibility rules listed below, as well as on considerations related to tool availability, part setup, and GCD accessibility.

Slot Milling is feasible only if all the following hold:

- If the slot either has a bathtub end or pitches up (creating a concavity in the floor), the floor is semi-circular. The GCD property **Min Floor Diameter** reflects an upper bound on the tool diameter that can be used for the smallest bathtub end or upward pitch on the slot. It is 0 if there is no bathtub end or upward pitch:
If Min Floor Diameter > 0 then Slot Type == SEMICIRCULAR_FLOOR
- (3-Axis Mill only): If the slot has pitch, it has a semicircular floor:
If Pitch == True then Slot Type == SEMICIRCULAR_FLOOR
- If the slot has fillets, they are symmetric (that is, the number of distinct fillet diameters is no greater than 1).

Groove Milling is feasible only if all the following hold:

- The slot has a straight trajectory (GCD property **Yaw** is **false**).
- Neither end of the slot is cylindrical (neither **End1 Type** is nor **End2 Type** is **Cylindrical**).
- If the slot either has a bathtub end or pitches up (creating a concavity in the floor), then the tool radius required to make that end or upward pitch is greater

than the slot depth. The GCD property **Min Floor Diameter** reflects the maximum *diameter* of such a tool required for the part:

$$\text{Min Floor Diameter} / 2 > \max(\text{Depth A}, \text{Depth B})$$

- Some groove mill tool can fit between the top of the slot wall and any obstruction above the wall. That is, for any **Is Accessible From** relation that relates the slot floor to a setup axis, if the relation is **Parallel Obstructed**, the **Distance to Obstruction** is at least 3 times the slot depth:

$$\text{Distance to Obstruction} \geq 3 * \min(\text{Depth A}, \text{Depth B})$$

Rough Milling is feasible only if all the following hold:

- If the slot has a flat floor and a bathtub end or upward pitch (**Max Floor Diameter** > 0), then it has corner fillets. (The upward pitch or bathtub end requires a ball end mill, which can only make edges or corners with fillets.)

For all three operations, feasibility also requires that a suitable setup axis can be found.

For Groove Milling, the cost model assumes that the tool is oriented normal to the slot walls. For Slot Milling and Rough Milling, the cost model generally assumes that one of the following tool orientations is used:

- Normal to the slot floor: this orientation is used only if it allows the tool to access all of the slot floor. This orientation is often preferred for flat floors.
- Parallel to the slot floor and walls: this orientation is used only if it allows the tool to access all of the floor. For Slot Milling, it is used only if the floor is semi-circular. This orientation is often preferred for low-aspect-ratio, semi-circular floor slots.
- Oblique to the slot floor: this orientation is used only if allows the tool to access all the surfaces of the slot.
- Parallel to the walls: for through slots (slots without floors), this orientation is used if it provides access to walls and ends.

Principal setup axes are preferred over non-principal setups that are used by other operations, which are preferred over non-principal setups that are *not* already in use (the cost model sometimes activates a new setup in order to make an operation possible).

In general, Slot Milling is preferred to Groove Milling is preferred to Rough Milling. Operation preferences and setup axis preferences interact according to internal heuristics in order to determine operation assignment.

Note that an operation is assigned only if a tool of the suitable type and diameter can be found--see [Tool Type Selection for Standard Slot Milling](#), [Diameter Selection for Slot Milling](#), [Tool Width Selection for Groove Milling](#), and [Diameter Selection for Slot Rough Milling](#).

Note also that if a slot's surfaces lie on a Parallel Surface Chain GCD, it is possible that these surfaces are created by a Perimeter Cut or Wire EDM Cut operation. In such a case, the slot GCD is not assigned the operations described in this section, but rather is assigned As Perimeter Cut or As Wire EDM Cut.

Deburring Operation Feasibility

Edge Deburring (Automated or Manual) is feasible only if all the following hold:

- Edge is sharp, that is, its **Edge Type** is neither **CHAMFER** nor **ROUND**.

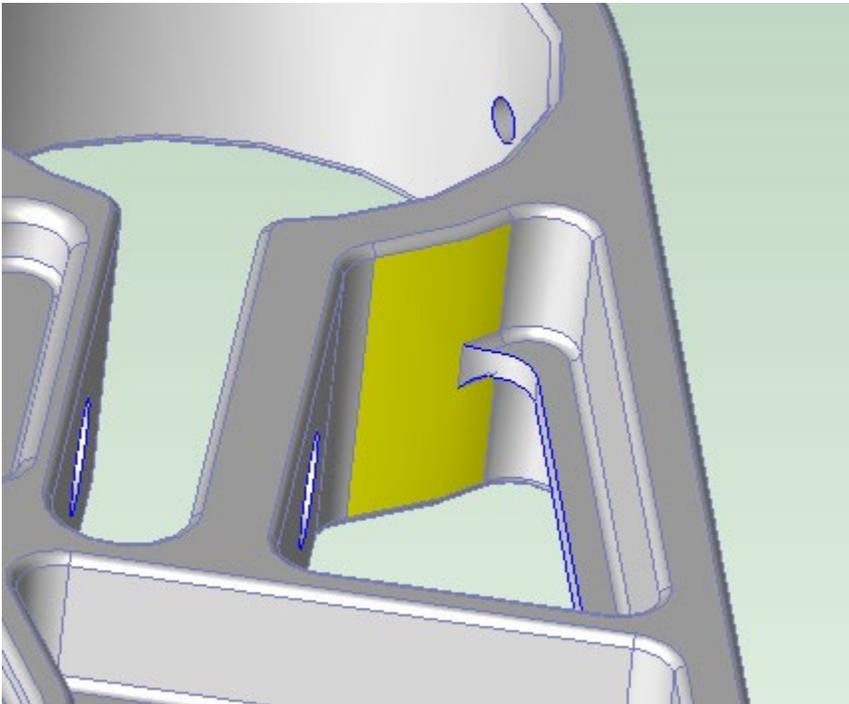
- Edge is not about a turning axis.
- Edge is formed by walls at a sufficiently small angle to one another, that is, the edge's **Max Wall Angle** or **Min Wall Angle** is no greater than the value of the cost model variable **deburrEdgeAngleCutOff** (150 degrees in starting point VPEs).

See also [Routing for Deburr Processes](#), for information on operation assignment.

Multiple Approach Surface Finishing

Finishing is usually performed on a given surface with a single operation that uses a single part setup and a single tool approach (see [Setup Axis GCDs](#)). However, in some cases, aPiori determines that finishing a given surface is best accomplished using a combination of different tool approaches and/or a combination of different operations. This can happen when there is no single tool approach from which *all* the surface is accessible to finishing or side milling (using a feasible tool).

Consider, for example, the surface highlighted in yellow, below:



For a tool approaching from the top (in this picture), some of the highlighted surface is obstructed by other surfaces, and so is inaccessible; similarly, for a tool approaching from the bottom, some of the surface is obstructed and so is inaccessible. But each point on the surface is accessible from one or the other approach, so aPiori assumes that one approach is used to side mill part of the surface, and the other approach is used to side mill the rest of the surface.

Multiple approach finishing is implemented by the following operation sequences, which are available for milling processes only:

Planar Face finishing:

- Mill Turn and 5Axis Mill
 - Facing->Side Milling

- Side Milling -> Side Milling
- Facing->Contouring
- 3Axis Mill and 4 Axis Mill:
 - Facing->Side Milling
 - Side Milling -> Side Milling

Curved Wall finishing:

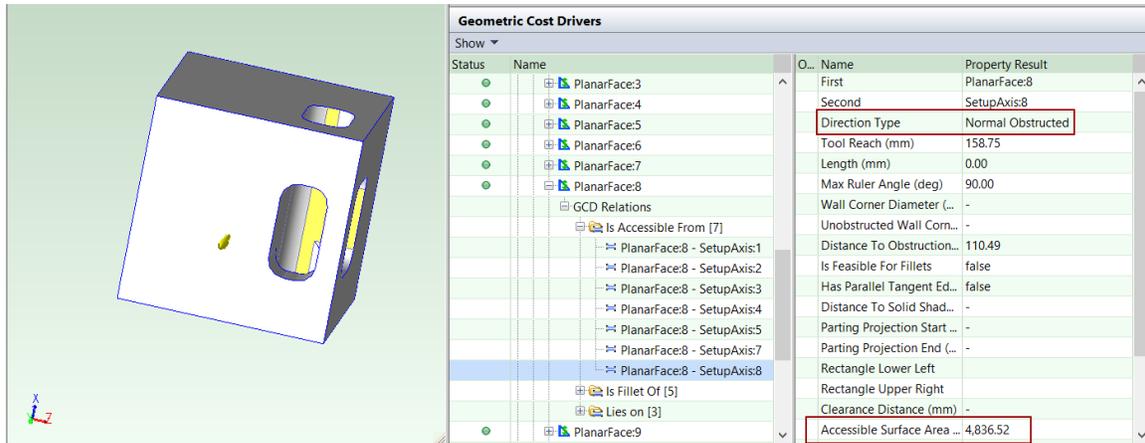
- Mill Turn, 5 Axis Mill, and 3 Axis Mill
 - Side Milling -> Side Milling
 - Side Milling -> Contouring
 - Contouring -> Contouring
- 4Axis Mill:
 - Side Milling -> Side Milling
 - Contouring->contouring

Multiple approach sequences are generally assigned to a surface only if all the following hold:

- Facing alone is infeasible.
- Side Milling alone from a single approach is infeasible.
- The surface does not have a user-assigned tool approach (specified with Assign SetupAxis from the context menu in the Geometric Cost Drivers pane).
- There are two partially obstructed tool approaches such that all the following hold:
 - For each of the two tool approaches, there is a valid part setup that allows the use of that approach. (With 3-Axis Mill routings, aPiori never activates a new part setup in order to accommodate multi-approach sequences.)
 - Each tool approach can access at least 2.5% of the GCD's surface area.
 - The sum of these two accessible areas is at least the GCD's total surface area.

For a surface and tool approach, The Direction Type property of the Is Accessible From relation indicates whether the approach is obstructed.

To find a surface's accessible area for a given tool approach, find the Accessible Surface Area property of the Is Accessible From relation that relates the surface and the tool approach:



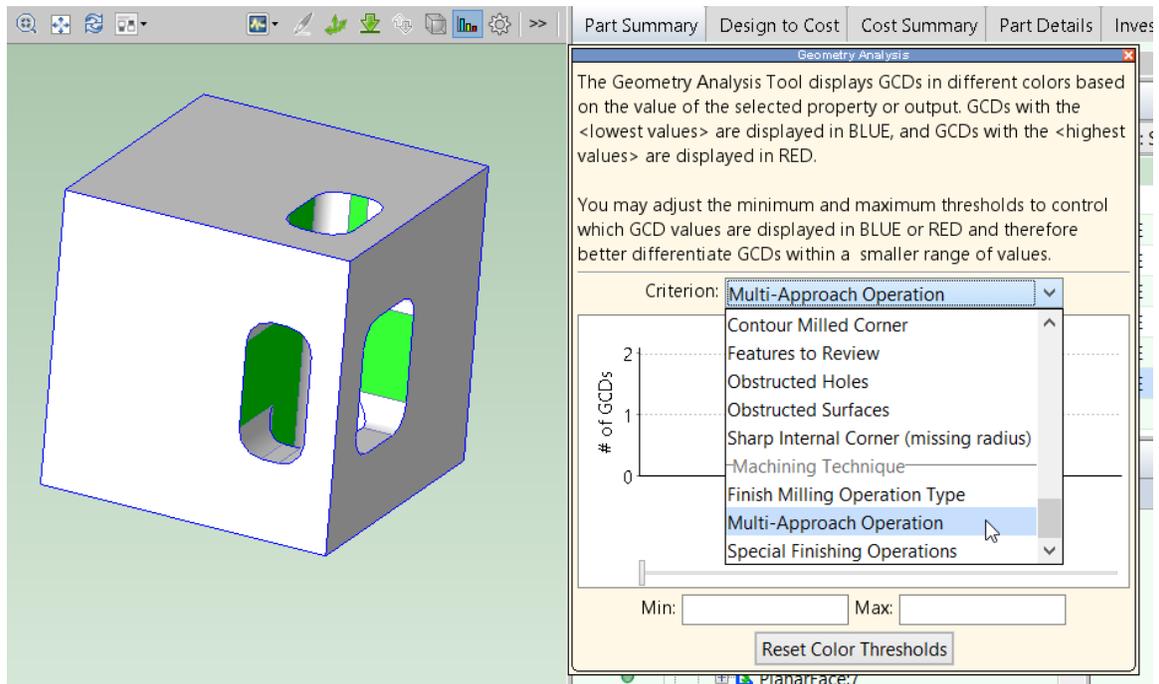
A surface's total surface area is given by the Finished Area property of the surface:

Geometric Cost Drivers			
Show ▾			
Status	Name	O... Name	Property Result
●	PlanarFace:3	Name	PlanarFace:8
●	PlanarFace:4	Finished Area (mm ²)	10,850.62
●	PlanarFace:5	Max Tool Diameter (mm)	-
●	PlanarFace:6	Tool Reach (mm)	0.00
●	PlanarFace:7	Bend Diameter (mm)	-
●	PlanarFace:8	Perimeter (mm)	762.00
	GCD Relations	SER Length (mm)	304.80
	Is Accessible From [7]	SER Width (mm)	76.20
	Is Fillet Of [5]	Corner Diameter (mm)	-
	Lies on [3]		

In general, given a multi-approach operation sequence, aPriori assumes that the more efficient operation finishes all of the surface that it has access to and the other operation finishes the remainder of the surface. For Side Milling/Side Milling or Contouring/Contouring, the first operation finishes all of the surface that it has access to and the second operation finishes the remainder of the surface.

Note that it is possible in rare cases that the two approaches do not have access to the entire surface, causing aPriori to underestimate the finishing time required. This can happen, for example, when full access from the first approach is prevented by multiple distinct obstructions; the second approach may access the area blocked by one obstruction to the first approach, but nevertheless fail to access the area blocked by another obstruction.

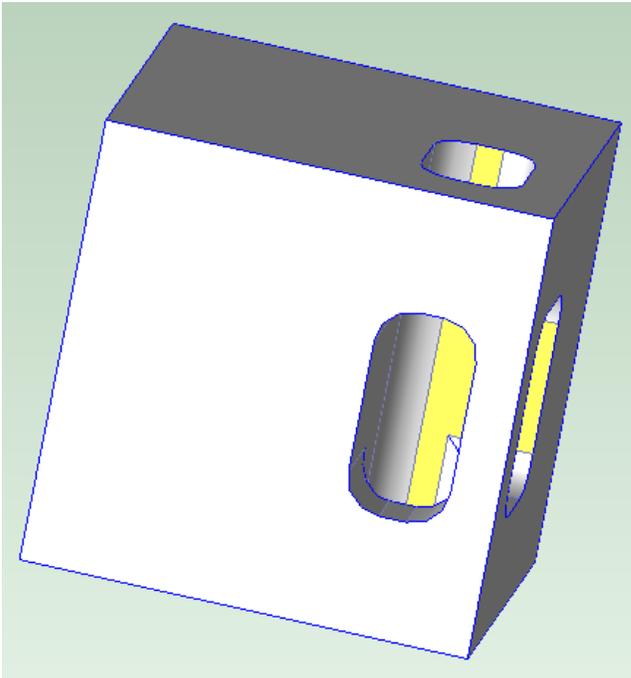
To highlight the surfaces that are finished with multi-approach sequences, select **Multi-Approach Operation** in the Criterion menu of the Geometry Analysis tool.



Note that, in addition to multiple-approach finishing, aPriori supports variable-approach finishing. With variable-approach finishing, available for 5-Axis Mill and Mill Turn routings, the tool orientation varies while the tool is engaged. This allows for a single operation that combines side milling and contouring or contouring from various angles—see Allow the Use of Flank Milling in [Machining Node Process Setup Options](#).

Examples: Side Milling/Facing

If Facing alone is not feasible for a planar face, and Side Milling alone, from a single approach, is also not feasible for the planar face, aPriori attempts to assign the sequence Side Milling/Facing to the surface. The illustration below shows a planar face (**PlanarFace8**, in yellow) to which aPriori assigns Side Milling/Facing:



For this surface, Facing alone is not feasible because the surface is partially obstructed from the approach that is normal to the surface. And Side Milling alone is not feasible for this surface, because the surface is partially obstructed from any approach parallel to the surface. But Facing and Side Milling can each access part of the surface. Therefore, aPriori assigns Side Milling/Facing to the surface.

Manufacturing Process

Status	Process Step	VPE	Machine
	Finishing		
	Facing		
●	PlanarFace:1	aPriori Base VPE	
●	PlanarFace:2	aPriori Base VPE	
●	PlanarFace:3	aPriori Base VPE	
●	PlanarFace:5	aPriori Base VPE	
●	PlanarFace:7	aPriori Base VPE	
●	PlanarFace:8	aPriori Base VPE	
	Side Milling		
●	CurvedWall:3	aPriori Base VPE	
●	CurvedWall:5	aPriori Base VPE	
●	CurvedWall:6	aPriori Base VPE	
●	CurvedWall:7	aPriori Base VPE	
●	CurvedWall:8	aPriori Base VPE	
●	CurvedWall:9	aPriori Base VPE	
●	CurvedWall:10	aPriori Base VPE	
●	CurvedWall:12	aPriori Base VPE	
●	PlanarFace:7	aPriori Base VPE	
●	PlanarFace:8	aPriori Base VPE	

Geometric Cost Drivers

Status	Name	Q...	Name	Property Result
●	PlanarFace:8		Name	PlanarFace:8
	GCD Relations		Finished Area (mm^2)	10,850.62
	Is Accessible From [7]		Max Tool Diameter (m...	-
	PlanarFace:8 - SetupAxis:1		Tool Reach (mm)	0.00
	PlanarFace:8 - SetupAxis:2		Bend Diameter (mm)	-
	PlanarFace:8 - SetupAxis:3		Perimeter (mm)	762.00
	PlanarFace:8 - SetupAxis:4		SER Length (mm)	304.80

(Note that Facing followed by Side Milling is shown as Side Milling/Facing in the Operation Sequence Selection dialog.)

In the illustration below, the yellow arrow shows the direction, **SetupAxis4**, from which the tool approaches for side milling. This part uses a 4-Axis Mill routing, and the upwards-

pointing purple arrow shows the part setup axis, which is aligned with the machine's axis of rotation.

Manufacturing Process

Status	Process Step	VPE	Machine
	Finishing		
	Facing		
●	PlanarFace:1	aPriori Base VPE	
●	PlanarFace:2	aPriori Base VPE	
●	PlanarFace:3	aPriori Base VPE	
●	PlanarFace:5	aPriori Base VPE	
●	PlanarFace:7	aPriori Base VPE	
●	PlanarFace:8	aPriori Base VPE	
	Side Milling		
●	CurvedWall:3	aPriori Base VPE	
●	CurvedWall:5	aPriori Base VPE	
●	CurvedWall:6	aPriori Base VPE	
●	CurvedWall:7	aPriori Base VPE	
●	CurvedWall:8	aPriori Base VPE	
●	CurvedWall:9	aPriori Base VPE	
●	CurvedWall:10	aPriori Base VPE	
●	CurvedWall:12	aPriori Base VPE	
●	PlanarFace:7	aPriori Base VPE	
●	PlanarFace:8	aPriori Base VPE	

Geometric Cost Drivers

Status	Name	O... Name	Property Result
●	PlanarFace:8	First	PlanarFace:8
	GCD Relations	Second	SetupAxis:4
	Is Accessible From [7]	Direction Type	Parallel Obstructed
	PlanarFace:8 - SetupAxis:1	Tool Reach (mm)	76.20
	PlanarFace:8 - SetupAxis:2	Length (mm)	76.20
	PlanarFace:8 - SetupAxis:3	Max Ruler Angle (deg)	0.00
	PlanarFace:8 - SetupAxis:4	Wall Corner Diameter (...)	50.80

Note that the Geometric Cost Drivers pane shows that the side milling tool approach has Parallel Obstructed as the Direction Type.

In the illustration below, the yellow arrow shows the tool approach, **SetupAxis8**, used for face milling. Note that the facing tool approach has Normal Obstructed as the Direction Type.

Manufacturing Process

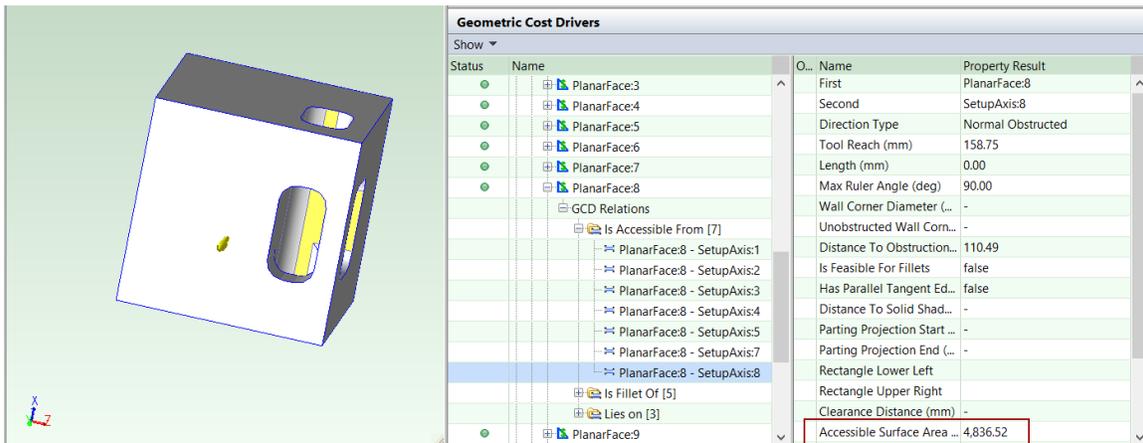
Status	Process Step	VPE	Machine
	Finishing		
	Facing		
●	PlanarFace:1	aPriori Base VPE	
●	PlanarFace:2	aPriori Base VPE	
●	PlanarFace:3	aPriori Base VPE	
●	PlanarFace:5	aPriori Base VPE	
●	PlanarFace:7	aPriori Base VPE	
●	PlanarFace:8	aPriori Base VPE	

Geometric Cost Drivers

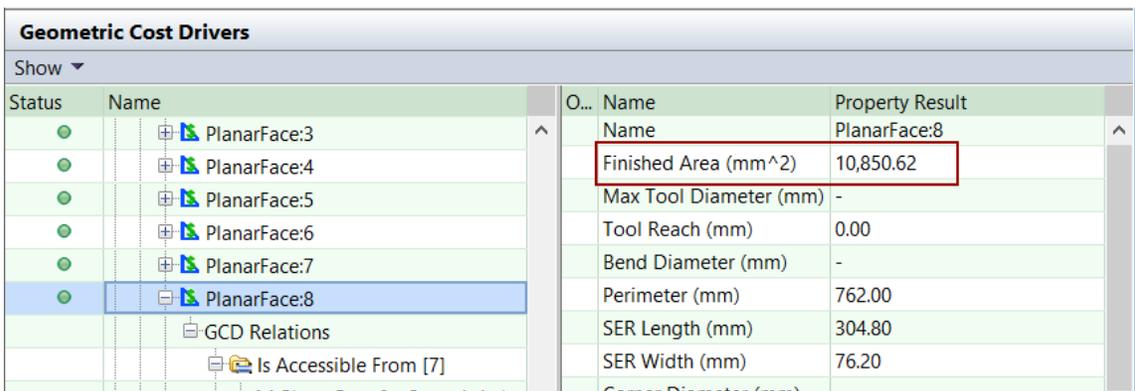
Status	Name	O... Name	Property Result
●	PlanarFace:8	First	PlanarFace:8
	GCD Relations	Second	SetupAxis:8
	Is Accessible From [7]	Direction Type	Normal Obstructed
	PlanarFace:8 - SetupAxis:1	Tool Reach (mm)	158.75
	PlanarFace:8 - SetupAxis:2	Length (mm)	0.00
	PlanarFace:8 - SetupAxis:3	Max Ruler Angle (deg)	90.00
	PlanarFace:8 - SetupAxis:4	Wall Corner Diameter (...)	-
	PlanarFace:8 - SetupAxis:5	Unobstructed Wall Cor...	-
	PlanarFace:8 - SetupAxis:7	Distance To Obstructio...	110.49
	PlanarFace:8 - SetupAxis:8	Is Feasible For Fillets	false
	Is Fillet Of [5]	Has Parallel Tangent E...	false
	Lies on [3]	Distance To Solid Shad...	-
●	PlanarFace:9	Parting Projection Start...	-
●	PlanarFace:10	Parting Projection End ...	-
●	PlanarFace:11	Rectangle Lower Left	-
●	PlanarFace:12	Rectangle Upper Right	-
●	PlanarFace:13	Clearance Distance (m...	-
●	PlanarFace:14	Accessible Surface Are...	4,836.52

aPriori assumes that Facing handles all of the surface that is accessible to Facing, and that Side Milling handles the remainder of the surface.

The surface's accessible area for the Facing tool approach (represented by **SetupAxis8**) is the value of the Accessible Surface Area property of the Is Accessible From relation that relates the surface and the tool approach:

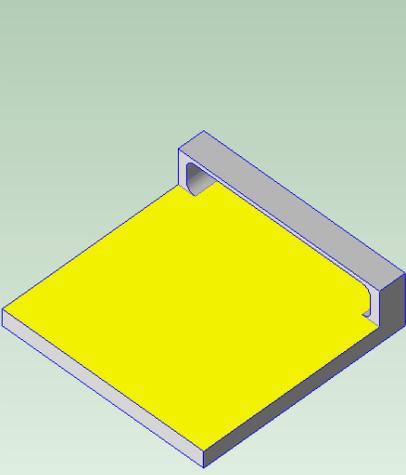


The surface's total surface area is given by the Finished Area property of the surface:



In this case, side milling is assumed to finish a surface area of $10,850.62 - 4836.52 = 6014.10\text{mm}^2$.

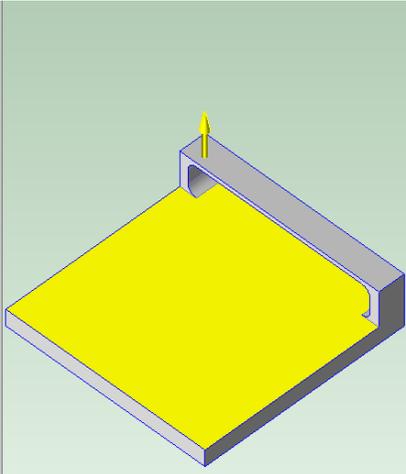
The illustration below shows another planar face (PlanarFace:2, in yellow) to which aPriori assigns Side Milling/Facing:



Status	Process Step	VPE	Machine
●	3 Axis Mill [3]	aPriori Base VPE	Virtual 3 Axis Mill - Small
●	Setup (SetupAxis:1)	aPriori Base VPE	
●	Setup:2 (SetupAxis:2)	aPriori Base VPE	
	Roughing		
	Finishing		
	Facing		
●	PlanarFace:2	aPriori Base VPE	
●	PlanarFace:7	aPriori Base VPE	
	Side Milling		
●	Setup:3 (SetupAxis:4)	aPriori Base VPE	
	Roughing		
	Finishing		
	Side Milling		
●	CurvedWall:1	aPriori Base VPE	
●	CurvedWall:2	aPriori Base VPE	
●	CurvedWall:3	aPriori Base VPE	
●	CurvedWall:4	aPriori Base VPE	
●	PlanarFace:2	aPriori Base VPE	
●	PlanarFace:9	aPriori Base VPE	

Geometric Cost Drivers			
Show			
Status	Name	O... Name	Property Result
●	Planar Faces [11]	Name	PlanarFace:2
●	PlanarFace:1	Finished Area (mm^2)	90,893.63
●	PlanarFace:2	Max Tool Diameter (mm)	-
●	PlanarFace:3	Tool Reach (mm)	304.80
●	PlanarFace:4	Bend Diameter (mm)	-
●	PlanarFace:5	Perimeter (mm)	1,219.20
●	PlanarFace:6	SER Length (mm)	304.80

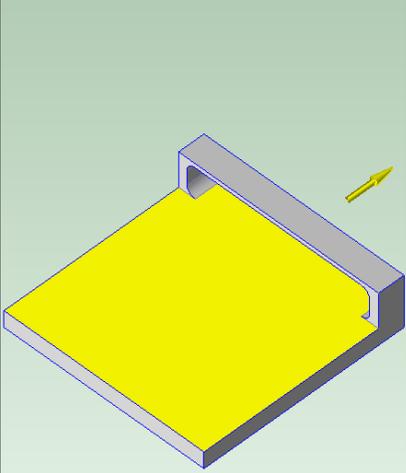
For this surface, Facing alone is not feasible because the surface is partially obstructed from the approach (SetupAxis:2) that is normal to the surface.



Status	Process Step	VPE	Machine
●	3 Axis Mill [3]	aPriori Base VPE	Virtual 3 Axis Mill - Small
●	Setup (SetupAxis:1)	aPriori Base VPE	
●	Setup:2 (SetupAxis:2)	aPriori Base VPE	
	Roughing		
	Finishing		
	Facing		
●	PlanarFace:2	aPriori Base VPE	
●	PlanarFace:7	aPriori Base VPE	
	Side Milling		
●	Setup:3 (SetupAxis:4)	aPriori Base VPE	
	Roughing		
	Finishing		
	Side Milling		
●	CurvedWall:1	aPriori Base VPE	
●	CurvedWall:2	aPriori Base VPE	
●	CurvedWall:3	aPriori Base VPE	
●	CurvedWall:4	aPriori Base VPE	
●	PlanarFace:2	aPriori Base VPE	
●	PlanarFace:9	aPriori Base VPE	

Geometric Cost Drivers			
Show			
Status	Name	O... Name	Property Result
●	PlanarFace:2	First	PlanarFace:2
	GCD Relations	Second	SetupAxis:2
	Is Accessible From [5]	Direction Type	Normal Obstructed
	PlanarFace:2 - SetupAxis:2	Tool Reach (mm)	54.10
	PlanarFace:2 - SetupAxis:3	Length (mm)	0.00
	PlanarFace:2 - SetupAxis:4	Max Ruler Angle (deg)	90.00
	PlanarFace:2 - SetupAxis:5	Wall Corner Diameter (m...	-

In addition, Side Milling alone is not feasible for this surface, not because of an obstruction, but because the tool reach would have to be too long compared to the tool's diameter (see Length to Diameter Ratio Check).



Status	Process Step	VPE	Machine
●	3 Axis Mill [3]	aPriori Base VPE	Virtual 3 Axis Mill - Small
●	Setup (SetupAxis:1)	aPriori Base VPE	
●	Setup:2 (SetupAxis:2)	aPriori Base VPE	
	Roughing		
	Finishing		
	Facing		
●	PlanarFace:2	aPriori Base VPE	
●	PlanarFace:7	aPriori Base VPE	
	Side Milling		
●	Setup:3 (SetupAxis:4)	aPriori Base VPE	
	Roughing		
	Finishing		
	Side Milling		
●	CurvedWall:1	aPriori Base VPE	
●	CurvedWall:2	aPriori Base VPE	
●	CurvedWall:3	aPriori Base VPE	
●	CurvedWall:4	aPriori Base VPE	
●	PlanarFace:2	aPriori Base VPE	
●	PlanarFace:6	aPriori Base VPE	

Geometric Cost Drivers			
Status	Name	O...	Property Result
●	PlanarFace:2	First	PlanarFace:2
	GCD Relations	Second	SetupAxis:4
	Is Accessible From [5]	Direction Type	Parallel Obstructed
	PlanarFace:2 - SetupAxis:2	Tool Reach (mm)	304.80
	PlanarFace:2 - SetupAxis:3	Length (mm)	304.80
	PlanarFace:2 - SetupAxis:4	Max Ruler Angle (deg)	0.00
	PlanarFace:2 - SetupAxis:5	Wall Corner Diameter (m...	25.40

But Facing and Side Milling can each access part of the surface. Therefore, aPriori assigns Side Milling/Facing to the surface.

Facing/Side Milling is available for the following processes:

- 3 Axis Mill
- 4 Axis Mill
- 5 Axis Mill
- Mill Turn

Examples: Side Milling/Side Milling

The operation sequence Side Milling/Side Milling can be assigned to a planar face or curved wall that is not fully accessible to side milling from any single tool approach, but can be side milled using a combination of two approaches.

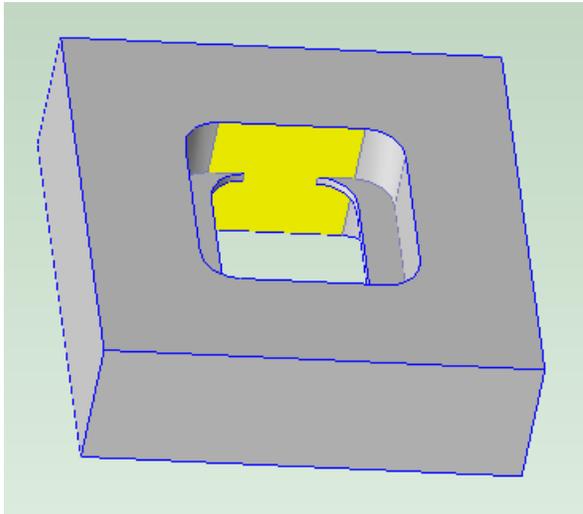
The operation sequence is used only if none of the following are feasible:

- Facing alone
- Side Milling alone
- Facing/Side Milling

Side Milling/Side Milling can be used for the following types of GCD:

- Planar faces
- Curved walls

The illustration below shows a planar face (in yellow) to which aPriori assigns Side Milling->Side Milling:



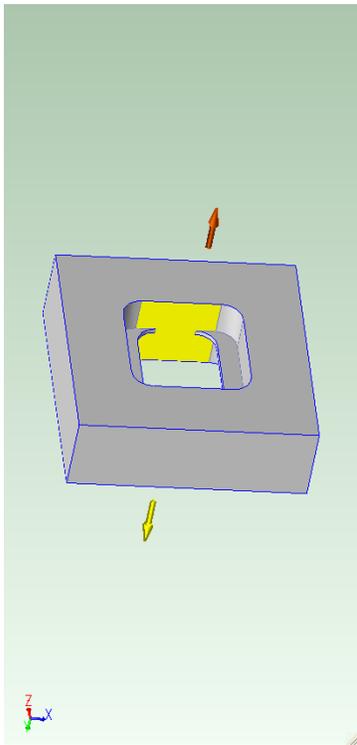
For this surface, Facing alone and Facing->Side Milling are not feasible because the surface is entirely obstructed from the approach that is normal to the surface. And Side Milling alone is not feasible for this surface, because the surface is partially obstructed from any approach parallel to the surface. But Side Milling from two different approaches can access all of the surface. Therefore, aPriori assigns Side Milling->Side Milling to the surface. (Side Milling followed by Side Milling is shown as Side Milling/Side Milling in the Operation Sequence Selection dialog.)

The arrows in the image below show the two directions (**SetupAxis:1** and **SetupAxis:2**) from which the tool approaches in order to perform side milling. Since this part uses a 3-Axis Mill machine, the two milling operations are performed using two different part setups.

Manufacturing Process			
Status	Process Step	VPE	Machine
●	Machining	aPriori Base VPE	
●	Band Saw	aPriori Base VPE	DoAll 3613-1 Vert
●	3 Axis Mill [2]	aPriori Base VPE	Virtual 3 Axis Mill - Small
●	Setup (SetupAxis:1)	aPriori Base VPE	
	Roughing		
	Finishing		
	Facing		
	Side Milling		
●	Setup:2 (SetupAxis:2)	aPriori Base VPE	
	Roughing		
	Finishing		
	Facing		
	Side Milling		
	Side Milling:2		
●	Bulk Milling	aPriori Base VPE	

Geometric Cost Drivers			
Status	Name	O... Name	Property Result
●	PlanarFace:9	Name	PlanarFace:9
	GCD Relations	Finished Area (mm^2)	9,999.98
	Is Accessible From [5]	Max Tool Diameter (mm)	-
	PlanarFace:9 - SetupAxis:1	Tool Reach (mm)	0.00
	PlanarFace:9 - SetupAxis:2	Bend Diameter (mm)	-
	PlanarFace:9 - SetupAxis:3	Perimeter (mm)	508.00
	PlanarFace:9 - SetupAxis:4	SER Length (mm)	101.60
	PlanarFace:9 - SetupAxis:6	SER Width (mm)	101.60
	Is Fillet Of [6]	Corner Diameter (mm)	0.00
	CurvedWall:12 - PlanarFace:9	Contour Corner Diameter (mm)	0.00

Both approaches have Parallel Obstructed as the Direction Type of the Is Accessible Relation between the surface and the approach.



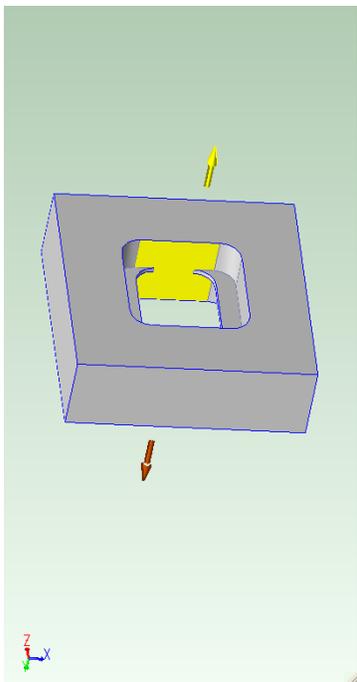
Component Information | **Production Information** | **Material Information**

Manufacturing Process

Status	Process Step	VPE	Machine
●	Machining	aPriori Base VPE	
●	Band Saw	aPriori Base VPE	DoAll 3613-1 Vert
●	3 Axis Mill [2]	aPriori Base VPE	Virtual 3 Axis Mill - Small
●	Setup (SetupAxis:1)	aPriori Base VPE	
	Roughing		
	Finishing		
	Facing		
	Side Milling		
●	Setup:2 (SetupAxis:2)	aPriori Base VPE	
	Roughing		
	Finishing		
	Facing		
	Side Milling		
	Side Milling:2		
●	Bulk Milling	aPriori Base VPE	

Geometric Cost Drivers

Status	Name	O... Name	Property Result
●	PlanarFace:9	First	PlanarFace:9
	GCD Relations	Second	SetupAxis:1
	Is Accessible From [5]	Direction Type	Parallel Obstructed
	PlanarFace:9 - SetupAxis:1	Tool Reach (mm)	101.60
	PlanarFace:9 - SetupAxis:2	Length (mm)	101.60
	PlanarFace:9 - SetupAxis:3	Max Ruler Angle (deg)	0.00
	PlanarFace:9 - SetupAxis:4	Wall Corner Diameter (mm)	50.80
	PlanarFace:9 - SetupAxis:6	Unobstructed Wall Corner ...	50.80
	Is Fillet Of [6]	Distance To Obstruction (m...	0.00
	CurvedWall:12 - PlanarFace:9	Is Feasible For Fillets	false



Manufacturing Process

Status	Process Step	VPE	Machine
●	Machining	aPriori Base VPE	
●	Band Saw	aPriori Base VPE	DoAll 3613-1 Vert
●	3 Axis Mill [2]	aPriori Base VPE	Virtual 3 Axis Mill - Small
●	Setup (SetupAxis:1)	aPriori Base VPE	
	Roughing		
	Finishing		
	Facing		
	Side Milling		
●	Setup:2 (SetupAxis:2)	aPriori Base VPE	
	Roughing		
	Finishing		
	Facing		
	Side Milling		
	Side Milling:2		
●	Bulk Milling	aPriori Base VPE	

Geometric Cost Drivers

Status	Name	O... Name	Property Result
●	PlanarFace:9	First	PlanarFace:9
	GCD Relations	Second	SetupAxis:2
	Is Accessible From [5]	Direction Type	Parallel Obstructed
	PlanarFace:9 - SetupAxis:1	Tool Reach (mm)	101.60
	PlanarFace:9 - SetupAxis:2	Length (mm)	101.60
	PlanarFace:9 - SetupAxis:3	Max Ruler Angle (deg)	0.00
	PlanarFace:9 - SetupAxis:4	Wall Corner Diameter (mm)	50.80
	PlanarFace:9 - SetupAxis:6	Unobstructed Wall Corner ...	50.80
	Is Fillet Of [6]	Distance To Obstruction (m...	0.00
	CurvedWall:12 - PlanarFace:9	Is Feasible For Fillets	false

The illustration below shows another surface (in yellow) to which aPriori assigns Side Milling/Side Milling. In this case, the two side milling approaches are orthogonal to each other. The arrows show the two directions (**SetupAxis:2** and **SetupAxis:3**) from which the tool approaches:

Status	Name	O...	Name	Property Result
●	PlanarFace:10	First	PlanarFace:11	
●	PlanarFace:11	Second	SetupAxis:3	
	GCD Relations	Direction Type	Parallel Obstructed	
	Is Accessible From [5]	Tool Reach (mm)	133.35	
	PlanarFace:11 - SetupAxis:1	Length (mm)	133.35	
	PlanarFace:11 - SetupAxis:2	Max Ruler Angle (deg)	0.00	
	PlanarFace:11 - SetupAxis:3	Wall Corner Diameter (mm)	50.80	
	PlanarFace:11 - SetupAxis:4	Unobstructed Wall Corner Dia	50.80	

aPriori assumes that the first operation handles all of the surface that is accessible to it, and that the second operation handles the remainder of the surface.

This operation sequence is available for the following processes:

- 3 Axis Mill
- 4 Axis Mill
- 5 Axis Mill
- Mill Turn

Example: Facing/Contouring

A planar face that is not fully accessible to face milling can sometimes be machined with a combination of facing and contouring. In such a case, aPriori may assign Facing/Contouring to the surface.

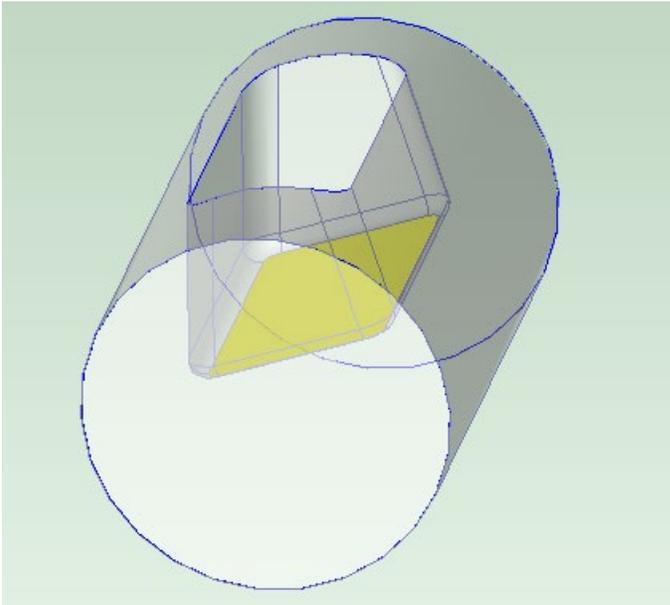
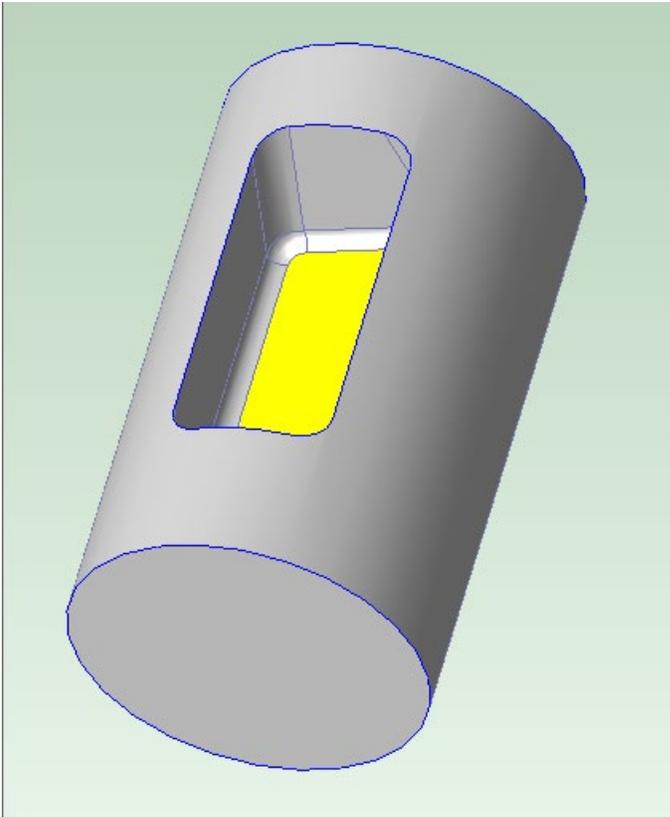
The operation sequence is used only if none of the following are feasible:

- Facing alone
- Side Milling alone
- Facing/Side Milling
- Side Milling/Side Milling

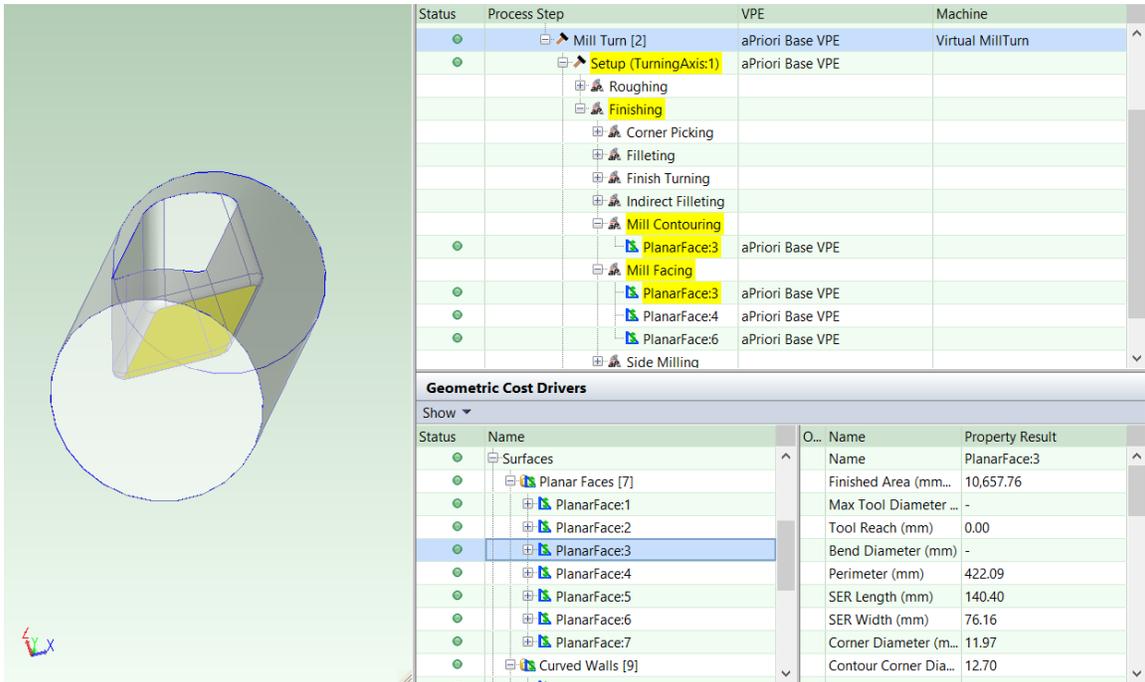
This operation sequence is available for the following processes:

- 5 Axis Mill
- Mill Turn

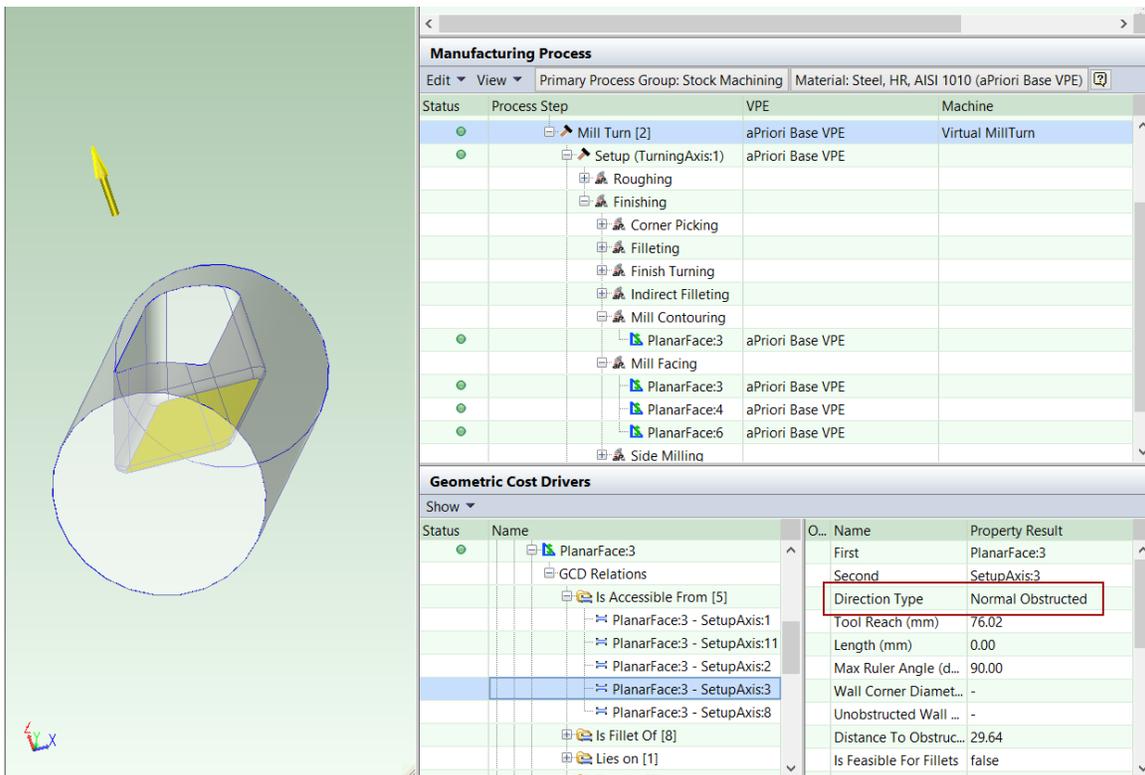
The following illustrations show a pocket whose floor (a planar face, in yellow) is partially obstructed by an angled side wall:



Face milling can access all of the surface except the undercut edge. If this part is routed to a Mill Turn routing (which must be selected manually), aPriori assigns Facing/Contouring to the surface.



In the image below, the yellow arrow shows the direction from which the face milling tool approaches.



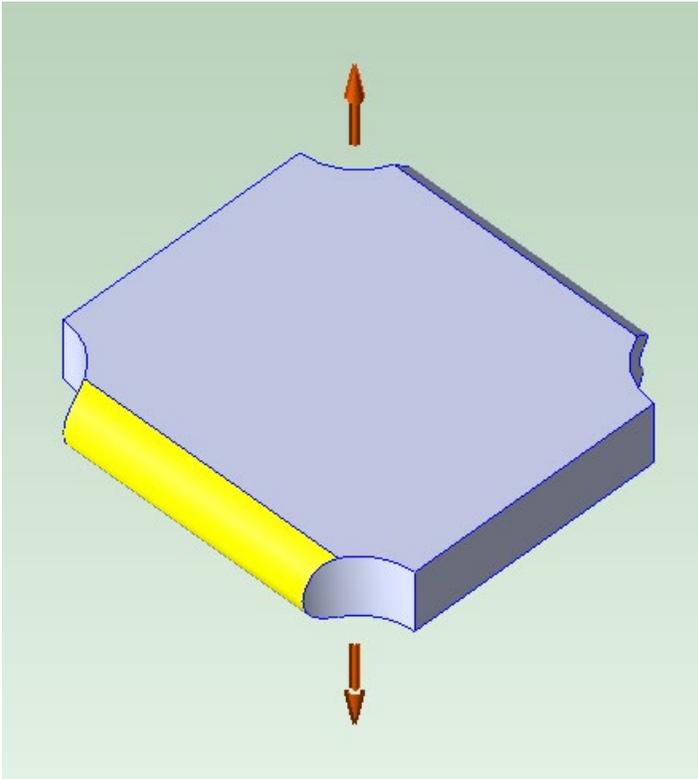
The Mill Turn machine can tilt the spindle and rotate the part around the turning axis so that the contoured region is accessible using the same part setup as was used for facing. aPriori assumes that Facing handles all of the surface that is accessible to Facing, and that Contouring handles the remainder of the surface.

Example: Contouring/Contouring

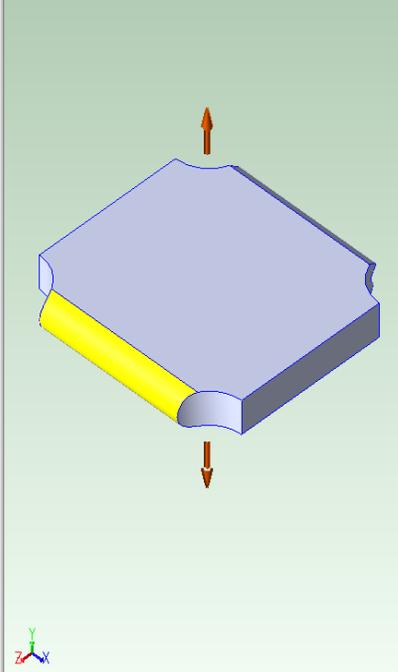
In some cases, aPiori determines that a curved wall should be finished with contouring that uses two different tool approaches. This can happen only if none of the following are feasible:

- Side Milling alone, from a single approach
- Contouring alone, from a single approach
- Side Milling/Side Milling
- Side Milling/Contouring

The image below shows a part with a curved wall (in yellow), half of which is accessible from the top, and half of which is accessible from the bottom.



If this part is routed to a 3-Axis Mill, the curved wall (CurvedWall:4) is assigned Contouring/Contouring, using two different part setups.



Status	Process Step	VPE	Machine
●	3 Axis Mill [2]	aPriori Base VPE	Virtual 3 Axis Mill - Small
●	Setup (SetupAxis:1)	aPriori Base VPE	
	Roughing		
	Finishing		
	Contouring		
●	CurvedWall:4	aPriori Base VPE	
	Facing		
	General Mill Finish		
	Side Milling		
●	Setup:2 (SetupAxis:2)	aPriori Base VPE	
	Roughing		
	Finishing		
	Contouring:2		
●	CurvedWall:4	aPriori Base VPE	
	Facing		

Geometric Cost Drivers			
Status	Name	O... Name	Property Result
●	CurvedWall:4	Name	CurvedWall:4
	GCD Relations	Finished Area (mm...	4,024.43
	Is Accessible From [4]	Max Tool Diameter ...	-
	CurvedWall:4 - SetupAxis:1	Tool Reach (mm)	109.19
	CurvedWall:4 - SetupAxis:2	Bend Diameter (mm)	-
	CurvedWall:4 - SetupAxis:3	Threaded	false
	CurvedWall:4 - SetupAxis:4	Thread Length (mm)	-
	Lies on [2]	Tolerance (coordina...	<unspecified>
●	CurvedWall:5	Roughness Ra (µm)	<unspecified>
●	CurvedWall:6	Roughness Rz (µm)	<unspecified>

Virtual Machining

Virtual machining allows users to estimate the cost of machining the following sorts of features:

- Features that are not actually modeled as solid geometry in the CAD model (as, for example, when a large number of holes are modeled as points rather than as solid material-removal features)
- Features that are modeled as material-removal features at the assembly level and thus not detected by aPriori (see [Assembly Machining](#)).

To use this capability, you must be aware of the assembly machining required and manually enter both the operation type and other relevant geometric information such as number of setups, workpiece material (if different from the default), hole diameters and depths, surface areas, and tool sizes. This information is entered via the Routing Editor and process setup options.

First you should select a routing that has the appropriate process. Certain operations of the following processes are supported:

- 3-Axis-Mill
- 4-Axis-Mill
- 5-Axis Mill
- Drill Press
- Deburr

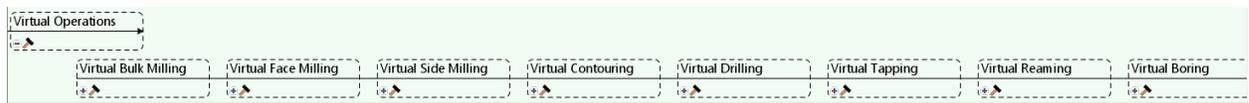
A **Virtual Operations** node is available in these routings, as shown below. Next, you should expand the routing and locate the new **Virtual Operations** node.

Use the Process Setup options on this node to specify the number of part setups (reorientations) required to machine the assembly.

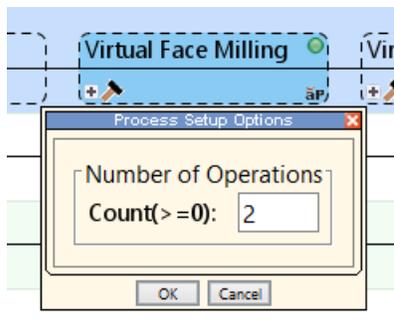
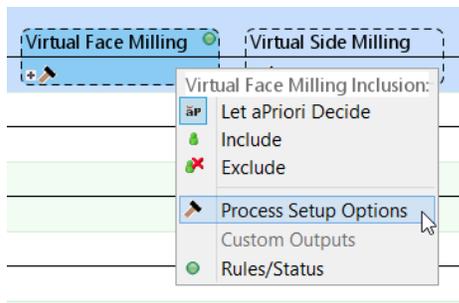
Next, expand the Assembly Operations node to view the available operations. The assembly machining operations available for manual assignment include the following:

- Bulk Milling,
- Face Milling,
- Side Milling
- Contouring
- Drilling
- Tapping
- Reaming
- Boring

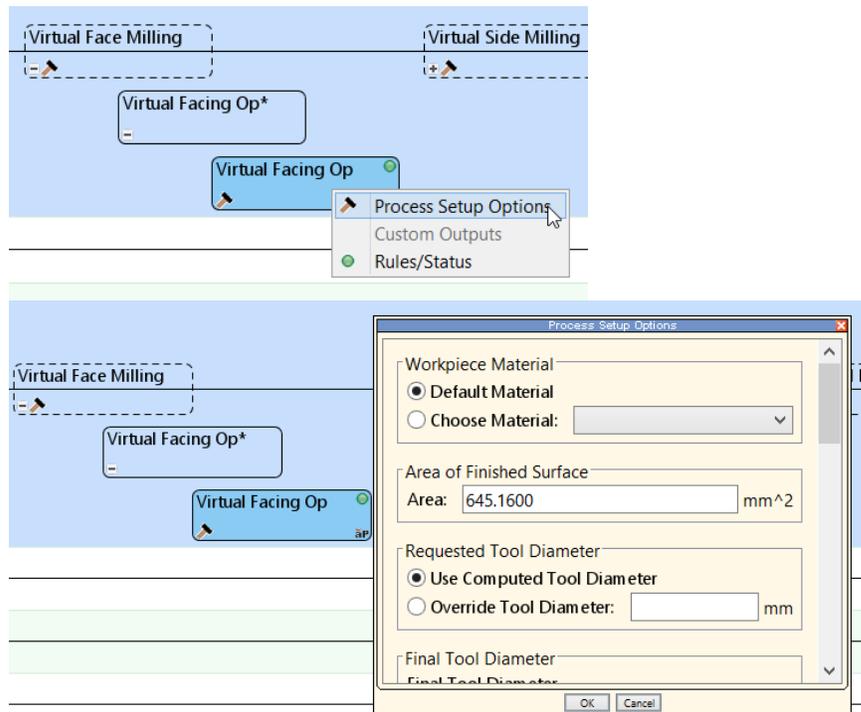
The operation names and are preceded with the word “Virtual” to identify that these are manually applied operations.



For each operation required for the assembly, indicate the number of instances of that operation by using a process setup option. Each instance of the operation represents one of a set of like features with identical dimensions and machining specifications. For example, if spot facing occurs in two locations on the assembly, indicate that there are two instances and provide the facing tool diameter and surface area to be faced for each instance.



Expand this node and its child to reveal the instance node. Use the process setup options on the instance node to enter other relevant geometric information



Tool Selection for Machining

For milling and drilling operations, tool selection does the following:

- Picks a tool diameter appropriate for the current operation and GCD. See [Diameter Selection for Surface Milling](#) and [Length to Diameter Ratio Check](#).
- Picks an appropriate tool series from the lookup table **tblSystemToolDeclarations**. See [Tool Series Selection](#).
- Establishes values for various tool properties, such as speed and feed. See [Tool Properties](#).

For turning operations, tool selection does the following:

- Picks an appropriate tool series from the lookup table **tblSystemToolDeclarations**. See [Tool Series Selection](#).
- Establishes values for various tool properties, such as speed and feed. See [Tool Properties](#).

Note that, unlike milling and drilling, turning tool selection does not select a tool diameter. With turning, the diameter relevant to speed and feed (see [Feeds and Speeds in the Machining Cost Model](#)) is the workpiece diameter rather than tool diameter (where the workpiece diameter is the diameter of a cross-section at the cut location normal to the turning axis).

This section has the following subsections:

- Diameter Selection
- Diameter Selection for Surface Milling
- Diameter Selection for Holemaking and Hole Finishing
- Diameter Selection for Pocket Roughing

- Diameter Selection for Dovetail Slot Finishing
- Diameter Selection for Slot Milling
- Tool Width Selection for Groove Milling
- Diameter Selection for Slot Rough Milling
- Diameter Selection for Stock Trim Roughing
- Diameter Selection for Planar Face Facing
- PSCs and Perimeters
- Diameter Selection for Side Milling
- Length to Diameter Ratio Check
- Tool Series Selection
- Tool Type Selection for Pocket Rough Milling
- Tool Type Selection for Standard Slot Milling
- Tool Type Selection for Deburring Operations
- Tool Properties
- Tool Selection for Keyway Broaching

Diameter Selection

Diameter selection is covered in the following sections:

- Diameter Selection for Surface Milling
- Diameter Selection for Holemaking and and Hole Finishing
- Diameter Selection for Pocket Roughing
- Diameter Selection for Dovetail Slot Finishing
- Diameter Selection for Slot Milling
- Tool Width Selection for Groove Milling
- Diameter Selection for Slot Rough Milling
- Diameter Selection for Stock Trim Roughing
- Diameter Selection for Planar Face Facing
- PSCs and Perimeters
- Diameter Selection for Side Milling
- Length to Diameter Ratio Check
- Boring Enlargement
- Diameter Selection for Side Milling

Diameter Selection for Surface Milling

For milling operations on surfaces, tool selection generally picks a tool diameter based in part on the following:

- Overall part size.

- The largest diameter small enough to produce the corners between the GCD and the adjacent convex walls. For many operations, this is specified by one of the following properties:
 - GCD property **Corner Diameter**
 - GCD property **Bend Diameter**
 - **Wall Corner Diameter** property of the **Is Accessible From** relation for the current GCD and the current operation's tool orientation--see [Setup Axes and Operation Feasibility](#). (This property takes into account the angle from which tool will approach; it is used for side milling.)
- Process-level setup options that constrain tool diameter:
 - **Maximum Facing Tool Diameter**
 - **Maximum Side Milling Tool Diameter**
 - **Maximum Contouring Tool Diameter**
- Machining node setup options that constrain tool diameter:
 - **Specify Maximum Radius for Indirect Filetting**
 - **Specify Maximum Radius for Rounding**
- Operation-level process setup option **Requested Tool Diameter**.
- Machine property **Max Mill Tool Diameter**.

For face milling of a planar face, diameter selection is also affected by process setup options that potentially constrain the total number of distinct tool diameters used for planar face facing:

- **Facing Maximum Tool Count**
- **Estimated Minimum Facing Diameter**
- **Estimated Maximum Facing Diameter**

See [Diameter Selection for Planar Face Facing](#) for more information on face milling of planar faces.

For side milling of a partially obstructed surface, tool diameter is sometimes constrained by the **Distance to Obstruction** property of the relevant **Is Accessible From** relation—see [Examples: Side Milling/Facing](#).

Diameter Selection for Holemaking and and Hole Finishing

For drilling operations, tool selection generally picks the GCD diameter as the tool diameter, or else it uses the diameter specified by an operation-level setup option, such as **Requested Tool Diameter** (see [Hole Making Options](#)).

For milling operations on holes, tool selection picks half the tool diameter, or else it uses the diameter specified by an operation-level setup option, such as **Requested Tool Diameter** (see [Hole Making Options](#)).

Large hole roughing and milling generally uses a flat end mill tool equal to 1/2 of the hole's diameter, up to the largest allowable end mill for the part. You can customize this fraction of the hole diameter with the cost model variable **largeHoleMillingDiameterRatio** (0.5 in starting point VPEs). The tool diameter is also constrained to be between 20% and 80% of the hole diameter.

For thread milling operations, tool selection picks 95% of the GCD diameter.

Diameter Selection for Pocket Roughing

Diameter selection picks either one or two diameters for roughing a given pocket. If two diameters are chosen, two occurrences of the Rough Milling operation are associated with the pocket. The first occurrence uses the larger diameter to remove most of the pocket's volume, and the second occurrence uses the smaller diameter (chosen to fit into the corners) to remove the remaining volume.

Users can override aPriori's choice of diameters with the setup option **Requested Percent Milled**—see [Pocket Rough Milling Options](#).

Default diameter selection for rough milling first preselects a diameter, snaps to down to a part-specific, industry-standard, preferred diameter.

Diameter preselection for pockets proceeds as follows:

- 1 Find the largest diameter that fits inside the pocket and into the pocket's corners; that is, choose the minimum of the following geometric properties:
 - o Corner Diameter
 - o SER Width
 - o SER Length

If the Corner Diameter is 0, do not choose a diameter in this step.

- 2 Pick a diameter that is a fraction of the pocket's **Inside Diameter**; in particular, choose the diameter that is the fraction of **Inside Diameter** specified by the cost model variable **maxRoughingInsideDiaPercentile** (0.85 in starting point VPEs), but no less than 50% of the **Inside Diameter**.
- 3 If a diameter was chosen in step 1, and it is less than the diameter chosen in step 2, the results of 1 and 2 are used as the preselected diameters. In this case, there will be two instances of the Roughing operation for the current GCD; the first will use the step 1's diameter as the preselected diameter, and the second will use step 2's diameter as the preselected diameter.

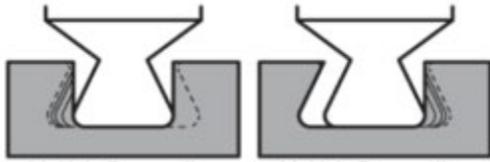
If the diameter chosen in step 1 is greater than or equal to the diameter chosen in step 2, the result of step 2 is used as the only preselected diameter. In this case, there will be one instance of the Roughing operation for the current GCD, and that instance will use step 2's diameter as the preselected diameter.

If no diameter was chosen in step 1, that is, if the **Corner Diameter** is 0, the cost model assumes that the corners of the actual part are not accurately reflected by the CAD model. In this case, the cost model further assumes that the diameter chosen in step 2 is small enough to fit into the actual corners, so the result of step 2 is used as the only preselected diameter.

The diameters of ball end mills are bounded above by the maximum values for the tool type specified in the lookup table **tblOperationSizeRanges**.

Diameter Selection for Dovetail Slot Finishing

Dovetail finishing uses a tool whose geometry is assumed to match the angle and depth of the slot-wall undercuts. In two or more passes, the tool removes the material that occupies the undercut portions of the slot.



This section describes default diameter selection. Users can override the default with the setup option **Override Tool Dimensions** (see [Dovetail Finishing Options](#)).

For a given dovetail slot, the cost model attempts to identify the *largest* diameter tool that meets the following requirements:

- The tool must be small enough to fit in a space from which it can initiate the first finishing pass:
 - For a *closed loop dovetail slot with no drop hole*, the tool must fit within the roughed slot. That is, tool diameter must be no greater than the roughed slot width (GCD property **Width**).

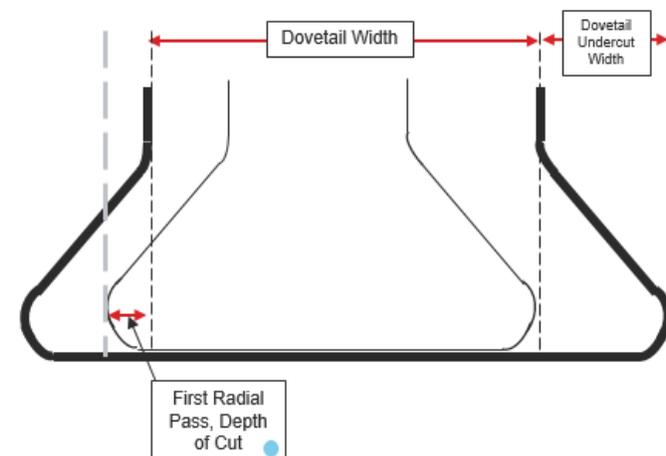
Tool Diameter \leq GCD Width

- For a *closed loop dovetail slot with a drop hole*, the tool must fit within the drop hole. That is, tool diameter must be no greater than the drop hole width (slot property **Throat Diameter**).

Tool Diameter \leq GCD Throat Diameter

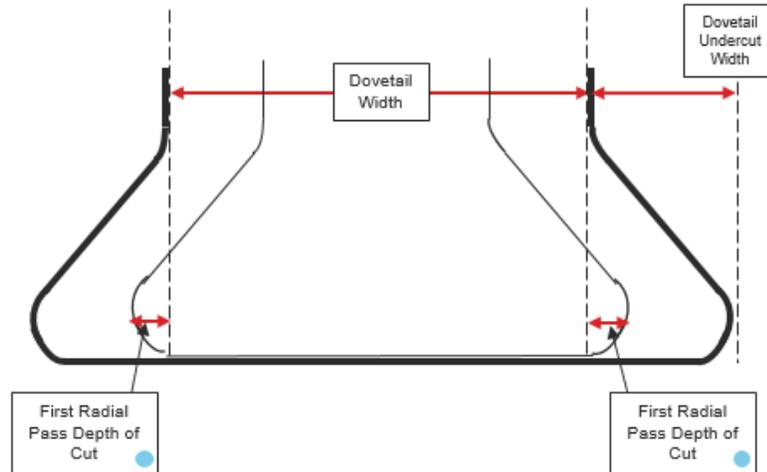
- For an *open-ended dovetail slot*, this criterion places no restriction on diameter.

- The tool must be small enough to cut at an appropriate radial depth in the first pass, given the width of the roughed slot:
 - For *conservative finishing* (see *Aggressive versus Conservative* in this section, below), the tool diameter must not exceed the rough slot width (GCD property **Width**) by more than the appropriate first-pass, per-side, radial cut depth.



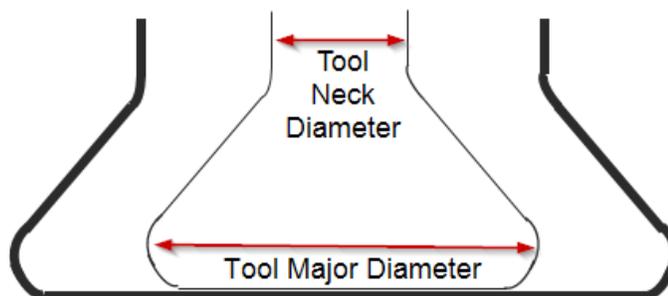
- For *aggressive finishing* (see *Aggressive versus Conservative* in this section, below), the tool diameter must not exceed the rough slot width (GCD property **Width**) by more than twice the appropriate first-pass, per-side, radial cut depth.

Tool Diameter \leq GCD Width + 2 * First-pass, Per-side, Radial Cut Depth



The appropriate first-pass, radial cut depth depends on slot depth, slot undercut width, and tool *neck* diameter, and is determined as described later in this section (see *Radial Cut Depth*, below).

- Tool diameter and tool *neck* diameter must be within range and appropriately proportioned with respect to one another and with respect to the slot depth (the larger of GCD properties **Dovetail Depth A** and **Dovetail Depth B**). The tool neck diameter is the difference between the tool *major diameter* (also known as the tool *major diameter*) and twice the slot undercut width (GCD property **Undercut Width A**):



In particular, all the following quantities must be within range (starting point VPE ranges are shown in parentheses):

- Tool neck diameter (bounded below by 0.35mm)
- Tool major diameter (bounded above by 25.4mm)
- Ratio of tool neck diameter to tool major diameter (bounded above by 1)
- Ratio of dovetail depth to tool major diameter (bounded above by 1.05)
- Ratio of dovetail depth to tool neck diameter (bounded above by 3.75)

The lookup table **tblOperationSizeRanges** specifies the acceptable range for each of these quantities.

Operation Name	Lower Bound	Upper Bound	Comment	Scale System
Finish Dovetail Milling	-1.00000	1.00000	Ratio of Neck Diameter / Major Diameter	absolute
Finish Dovetail Milling	-1.00000	1.05000	Ratio of Dovetail Depth / Major Diameter	absolute
Finish Dovetail Milling	-1.00000	3.75000	Ratio of Dovetail Depth / Neck Diameter	absolute
Finish Dovetail Milling	0.00000	25.40000	Major Diameter Limit	absolute
Finish Dovetail Milling	0.35000	-1.00000	Neck Diameter Limit	absolute
Finish Dovetail Milling	30.00000	-1.00000	Wall Angle	absolute
Finish Dovetail Milling	0.00000	0.50000	Neck Diameter Limit	absolute

A value of -1 indicates that the range is unbounded on one end.

See [Slot Properties](#) for more information on the GCD properties mentioned in this section.

Tool selection fails if aPriori can find no tool that meets the selection criteria. In starting point VPEs, tool selection also fails if the slot walls form an angle of less than 30 degrees with the slot floor. This lower bound on the wall angle (GCD property **Wall Angle A**) is specified in the lookup table **tblOperationSizeRnages**.

If tool selection fails for Finish Dovetail Milling, the operation General Finish Dovetail Milling is used instead.

Aggressive versus Conservative

By default in starting point VPEs, aPriori attempts to select a tool under the assumption that the tool will cut both sides of the roughed slot at once during the first finishing pass. If no such tool can be found, tool selection fails.

VPE Administrators can change the default by setting the cost model variable **preferAggressiveDovetailCuttingMethod** to **false**. In this case, aPriori attempts to select a tool under the assumption that the tool will cut only one side of the roughed slot during the first finishing pass. If no such tool can be found, aPriori attempts to select a tool under the assumption that the tool will cut both sides of the roughed slot at once during the first finishing pass. If no such tool can be found, tool selection fails.

Users can override the default with the setup option Cutting Method on First Pass (see [Dovetail Finishing Options](#)). In this case, aPriori attempts to select a tool only under the assumption specified by the setup option. If no such tool can be found, tool selection fails.

Radial Cut Depth

First-pass, per-side, radial cut depth is determined as follows:

- 1 Determine the number of passes required, based on slot depth and tool neck diameter: this uses a heuristic derived from a large, representative data sample. The heuristic represents the number of passes as a linear combination of tool neck diameter and slot depth (the larger of the GCD properties **Dovetail Depth A** and **Dovetail Depth B**).
- 2 Look up by number of passes the percent of total undercut width to be removed in the first pass: this uses the lookup table **tblDovetailFinishingPassCharacteristics**:

Number Of Passes	Pass 1 (%)	Pass 2 (%)	Pass 3 (%)	Pass 4 (%)	Pass 5 (%)
2	70	30			
3	50	30	20		
4	46	25	18	11	
5	46	25	16	8	5
6	43	22	16	10	6
7	38	22	16	11	8
8	32	21	16	12	9
9	30	20	16	12	9
10	27	19	15	12	9
11	25	18	14	12	9
12	23	17	13	11	8
13	21	16	13	11	9
14	19	15	13	11	9
15	16	13	12	11	9
16	13	11	10	10	0

- 3 The first-pass cut depth is this percentage of the slot's undercut width (GCD property **Undercut Width A**).

Diameter Selection for Slot Milling

For a given slot, the cost model selects the largest standard tool diameter that doesn't exceed the slot width.

Tool selection fails if this diameter is out of range for the tool series, or if it exceeds either of the following upper bounds on tool diameter:

- Upper Bound specified in the lookup table **tblOperationSizeRanges** for Slot Milling and the current tool type (**Flat End Mill** or **Ball End Mill**).
- Percentage of the part's size specified in the lookup table **tblOperationSizeRanges** for Slot Milling and the current tool type (**Flat End Mill** or **Ball End Mill**)--12% in starting point VPEs. The part size, here, is the sum of the two smaller dimensions among length, width, and height.

In addition, the tool's length-to-diameter ratio must be less than the cost model variable **easyL2DRatio** (3 in starting point VPEs) or the setup option Specify Easy Side Milling Length to Diameter Ratio (see [Machining Node Process Setup Options](#)).

Tool Width Selection for Groove Milling

The cost model selects a tool width that is the smaller of the following:

- Slot width
- The maximum tool width appropriate for the slot, based on a number of factors, including the current tool series, groove depth, material cut code, and tool type (see **Max Groove Width** in the lookup table **tblGrooveMilling**), as well as the geometric property **Min Floor Diameter** (diameter of the tightest upward curve in the slot floor and ends).

Once the tool width is established, the diameter is looked up by tool series, tool width, groove depth, material cut code, and tool type in the lookup table **tblGrooveMilling**.

Tool selection fails if the tool diameter is out of range, or if the diameter is too large to make the tightest upward curve in the floor (as specified by the geometric property **minFloorDiameter**).

Diameter Selection for Slot Rough Milling

For a given slot, the cost model attempts to identify the largest diameter that does not exceed any of the following upper bounds on tool diameter:

- Slot Width
- Upper Bound specified in the lookup table **tblOperationSizeRanges** for Rough Milling and the current tool type (**Flat End Mill** or **Ball End Mill**, in the Comment field)
- Upper Bound specified in the lookup table **tblOperationSizeRanges** for Rough Milling and the tool type Face Mill (in the Comment field)
- Machine property **Max Mill Tool Diameter**
- Percentage of the part's size specified in the lookup table **tblOperationSizeRanges** for *Slot Milling* and the current tool type (**Flat End Mill** or **Ball End Mill**)--12% in starting point VPEs. The part size, here, is the sum of the two smaller dimensions among length, width, and height.

Tool selection fails if this diameter is out of range for the tool series.

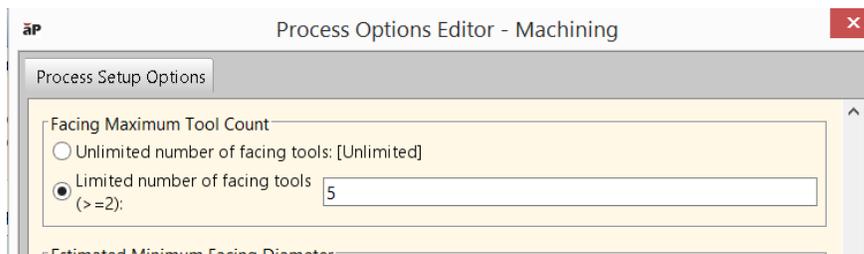
In addition, the tool's length-to-diameter ratio must be less than the cost model variable **easyL2DRatio** (3 in starting point VPEs) or the setup option Specify Easy Side Milling Length to Diameter Ratio (see [Machining Node Process Setup Options](#)). Tool length is the slot length, for a tool whose axis is oriented parallel to the slot floor.

Diameter Selection for Stock Trim Roughing

By default, roughing performed on a part's Stock Trim GCD is assumed to use the same tool as roughing on the part's Bulk Removal GCD. You can override the default behavior, and assign distinct tool diameters, and even a separate Stock Prep Mill process if desired.

Diameter Selection for Planar Face Facing

By default in starting point VPEs, the total number of distinct tool diameters used for face milling the current part's planar faces is limited to 4, 5, or 6, depending on part geometry (see *Part-specific Preferred Diameters*, below). VPE administrators can customize the default maximum limit with the cost model variable **maxFacingToolsDefault**. Users can customize or remove the limit with the setup option **Facing Maximum Tool Count** (defined on the **Machining** node).



The setup option has two modes:

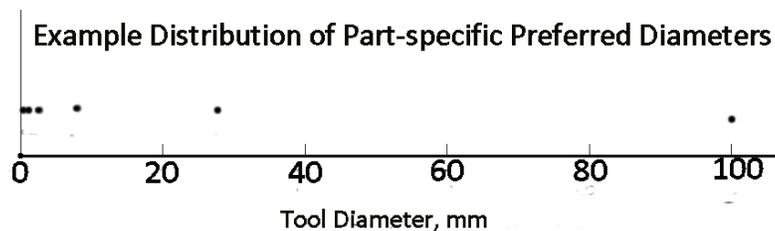
- Unlimited number of facing tools: in this case, potentially, each faced surface uses a distinct tool diameter.
- Limited number of facing tools: this is the default mode. Users can enter a limit explicitly.

If the number of tools is unlimited, tool selection for planar face facing follows these steps:

- 1 *Preselect* a diameter based on the surface's geometry. Preselection chooses a theoretically ideal tool size, taking into account the corner diameters of any surrounding walls. For details, see *Preselected Diameters*, below.
- 2 Snap down the preselected diameter to the nearest industry-standard tool size; that is, select the largest industry-standard tool size that is less than or equal to the pre-selected size. Industry standard tool sizes are listed in the lookup table **tblPreferredSizes** in the Machining process group.

If the number of tools is limited to N distinct tool diameters, then the cost model forms a list of N preferred diameters based on the geometry of all the part's planar faces that are accessible to facing (see *Part-specific Preferred Diameters*, below). The list includes at least 4 standard tool diameters. Only preferred diameters are used for facing, but they are not necessarily all used. In this case, tool selection follows these steps:

- 1 *Preselect* a diameter based on the surface's geometry. Preselection chooses a theoretically ideal tool size, taking into account the corner diameters of any surrounding walls. For details, see *Preselected Diameters*, below.
- 2 Snap down the preselected diameter to the nearest *preferred* size. The preferred sizes consist of N industry-standard tool diameters spread out between the minimum and maximum, snapped-down, preselected diameters for the part as a whole. The preferred diameters are *not* evenly spread out from the minimum to the maximum, but rather are more tightly clustered near the minimum and are more spread out towards the maximum.

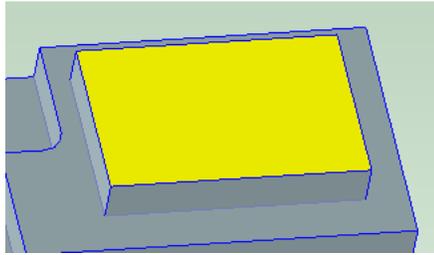


For details, see *Part-specific Preferred Diameters*, below.

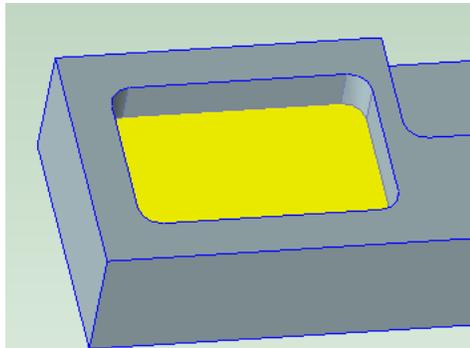
Users can override the maximum and minimum preferred diameters with the setup options **Estimated Minimum Facing Diameter** and **Estimated Maximum Facing Diameter** (defined on the Machining node).

Preselected Diameters: Diameter preselection for a given planar face depends on whether the surface is raised, sunken (almost entirely surrounded by concave walls), or partially sunken (partially surrounded by concave walls):

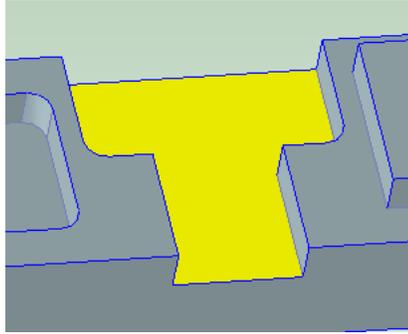
- **Raised:** A planar face is considered raised if its **Percent Concave Perimeter** property is 0. In this case, preselection picks the largest tool that is small enough to satisfy all the following selection criteria:



- Smaller than the current machine's maximum diameter
 - Smaller than the selected tool series' maximum diameter
 - Smaller than the maximum diameter appropriate for the part (calculated based on the largest two dimensions of the part's bounding box)
 - Smaller than the maximum diameter for face mill facing listed in the lookup table **tblOperationSizeRanges**
- **Sunken:** A planar face is considered sunken if its **Percent Concave Perimeter** property is 98% or more. In this case, preselection picks the largest tool that is small enough to satisfy all the following selection criteria:



- Small enough to fit in all the surface's corners (as indicated by the property **Corner Diameter**)
 - Diameter less than or equal to 80% of the largest diameter that can access at least 80% of the surface
 - Smaller than the current machine's maximum diameter
 - Smaller than the selected tool series' maximum diameter
 - Smaller than the maximum diameter appropriate for the part (calculated based on the largest two dimensions of the part's bounding box)
 - Smaller than the maximum diameter for face mill facing listed in the lookup table **tblOperationSizeRanges**
- **Partially sunken:** A planar face is considered partially sunken if its **Percent Concave Perimeter** property is greater than 0 and less than 98%.



In this case, if there are non-negligible corners (the face's **Corner Diameter** is greater than or equal to 0.254mm), preselection does one of the following:

- If 90% or more of the planar face is the floor of a slot (see **Slot GCD**), and the width of the slot's fillets (if any) is less than 25% of the slot width, the preselected diameter is equal to the slot width. (90%, here, is used in Starting point VPEs; the value can be customized with the cost model variable **areaOfSurfaceInSlot**. Similarly, 25%, here, is used in starting point VPEs; the value can be customized with the cost model variable **filletCoverageForFacingOfSlotFloor**.)
- Otherwise, preselection picks the largest tool that is small enough to fit in the corners. If there are *no* non-negligible corners, tool selection picks a diameter that is the weighted average of (1) the diameter that would be chosen if the surface were raised, and (2) the diameter that would be chosen if the surface were sunken (see above). The first term is weighted by the fraction of the surface's perimeter that is not surrounded by a wall, and the second term is weighted by the fraction of the surface's perimeter that is surrounded by walls (as specified by **Percent Concave Perimeter**).

Note: Diameter selection ignores corners that are, in the CAD model, smaller than any realistic mill diameter (that is, smaller than 0.254mm, the smallest preferred number in the US unit system). In such a case, it is assumed that the corners of the actual part are not accurately reflected by the CAD model. The cost model assumes that the tool selected based on the other selection criteria (see above) is small enough to fit into the actual corners.

Part-specific Preferred Diameters: Tool selection follows these steps in order to find the preferred diameters:

- 1 Find the total number, n , of distinct, preselected diameters (see *Preselected Diameters*, above), taking into account all the part's planar faces that are accessible from a direction normal to the face.
- 2 Determine the total number, N , of part-specific preferred diameters. By default, this is determined from n (found in step 1) as follows:

$$N = \max(\min(6, \text{roundup}(0.4n + 2.5)), 4)$$

In other words, by default,

- N is $\text{roundup}(0.4n + 2.5)$, if $\text{roundup}(0.4n + 2.5)$ is between 4 and 6.
- N is 4, if $\text{roundup}(0.4n + 2.5)$ is less than 4.
- N is 6, if $\text{roundup}(0.4n + 2.5)$ is greater than 6.

Users can override the default, and specify N explicitly—see **Facing Maximum Tool Count** in [Machining Node Process Setup Options](#)

- 3 Find the maximum and minimum preferred diameters. By default, these are the minimum and maximum diameters found in step 1, snapped down to the nearest industry-standard tool size. Industry-standard tool sizes are listed in the lookup table **tblPreferredSizes**. Users can override the maximum and minimum with the setup options **Estimated Minimum Facing Diameter** and **Estimated Maximum Facing Diameter** (defined on the Machining node).
- 4 Form a Renard sequence of N preferred diameters as follows (where N is defined in step 2, above): form a geometric progression starting with the minimum diameter and ending with the maximum diameter (found in step 3), where the ratio of each pair of successive terms is the $N-1$ root of the ratio of the maximum diameter to the minimum diameter, that is, where the common ratio of the geometric progression is

$$\text{(Maximum Diameter/Minimum Diameter)}^{1/(N-1)}$$
- 5 Snap down each member of the Renard sequence to the nearest industry-standard tool size (except the maximum and minimum, which are already snapped down). These snapped-down values are the part-specific preferred tool sizes.

Using a Renard sequence in this way generally minimizes the discrepancies (as a percentage of diameter) between the preselected diameters and the preferred diameters.

PSCs and Perimeters

Operation assignment and diameter selection for side milling rely on information about two special GCD types:

- Perimeter GCD
- Parallel Surface Chain (PSC)

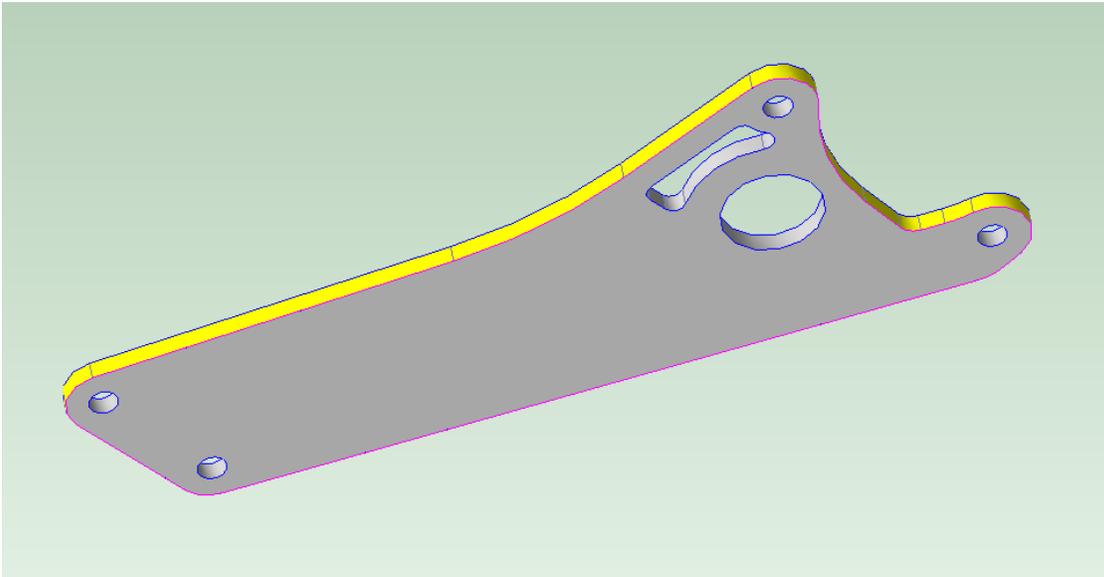
It is often possible (and desirable) for all the surfaces that *lie on* a perimeter or PSC to be side milled using a single setup and a single tool. (See also [Diameter Selection for Side Milling](#).)

A perimeter GCD is the closed boundary around the projection of a part onto a plane normal to the part's length, width, or depth direction (that is, the length, width, or depth direction of the part's bounding box, where height \leq width \leq length).

Each part has three external perimeters:

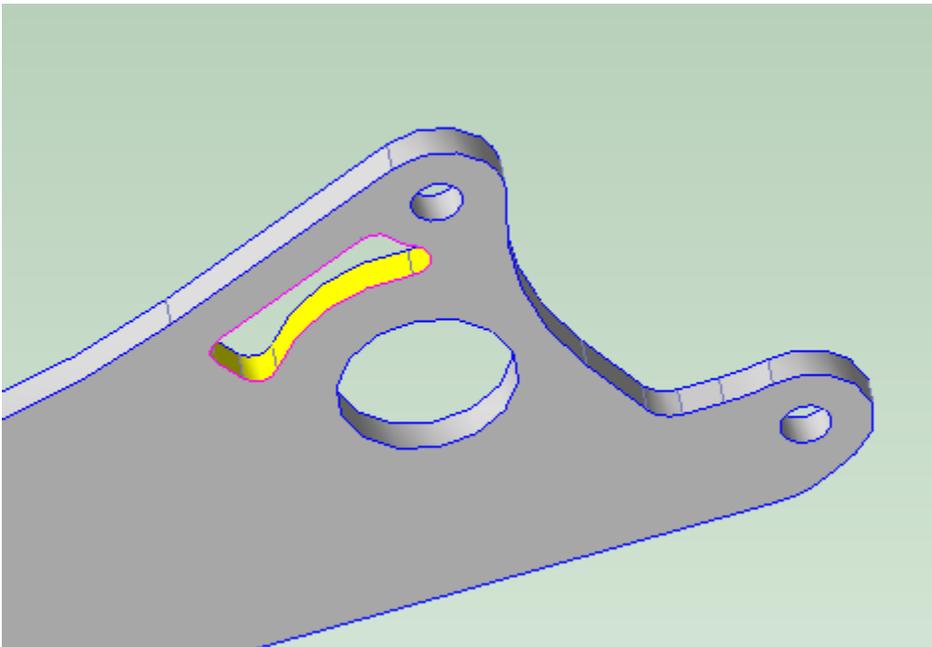
- Height-direction perimeter: contained in a plane normal to the height direction.
- Width-direction perimeter: contained in a plane normal to the width direction.
- Length-direction perimeter: contained in a plane normal to the length direction.

A part might also have internal perimeters due to internal, through-all cut-outs.



Shown in pink is this part's height-direction perimeter, which lies in a plane normal to the height direction. The walls that lie on this perimeter are shown in yellow.

The following image shows an internal perimeter in pink, with surfaces that lie on the perimeter in yellow:



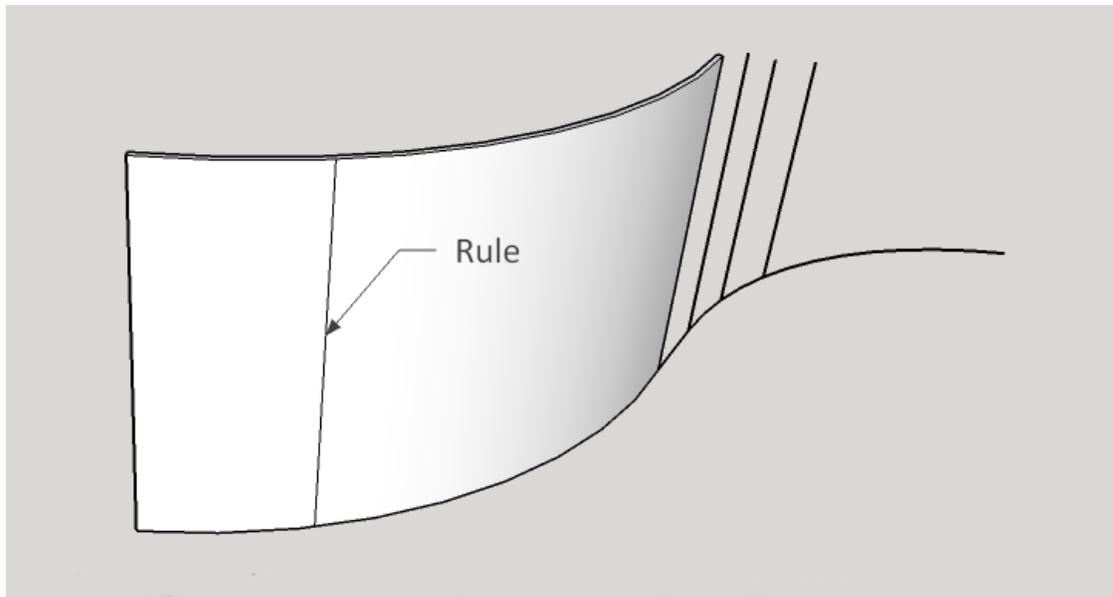
An internal perimeter is shown in pink. The walls that lie on this perimeter are shown in yellow.

The **LIES ON** relation between surfaces and perimeters is shown in the Geometric Cost Drivers pane. A planar face lies on a perimeter if both the following hold:

- Planar face contains line segments that are normal to the plane containing the perimeter.
- For each such line segment there is a line that contains both the line segment and some point on the perimeter.

A curved wall lies on a perimeter if both the following hold:

- Rules of the curved wall are normal to the plane containing the perimeter.
- For each such rule there is a line that contains both the rule and some point on the perimeter.

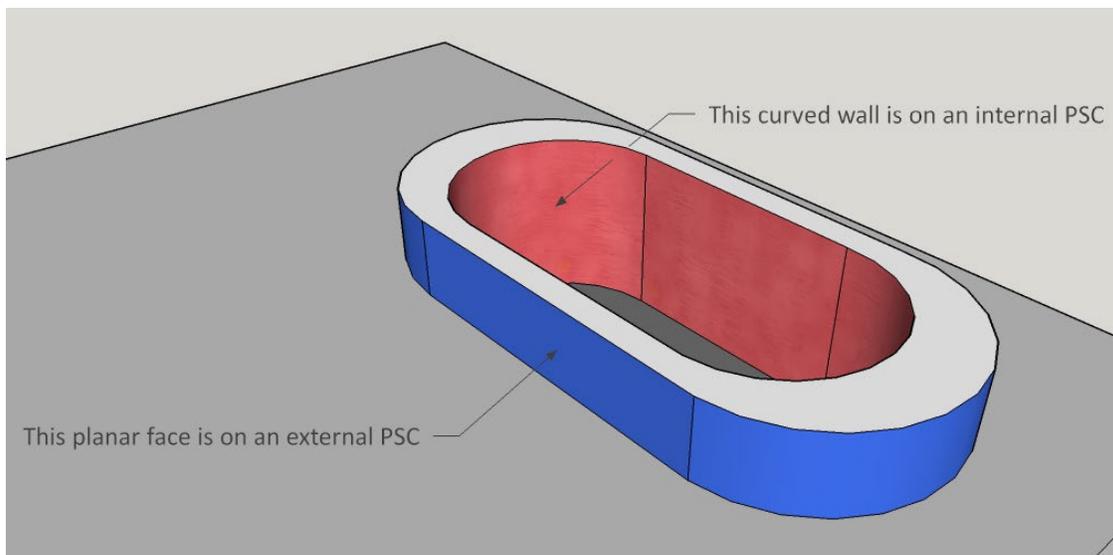


A curved wall is described by a rule translated along a smooth curve.

A parallel surface chain (PSC) is a non-perimeter GCD that consists of a closed loop of planar faces and curved walls that are all parallel to each other in the following sense:

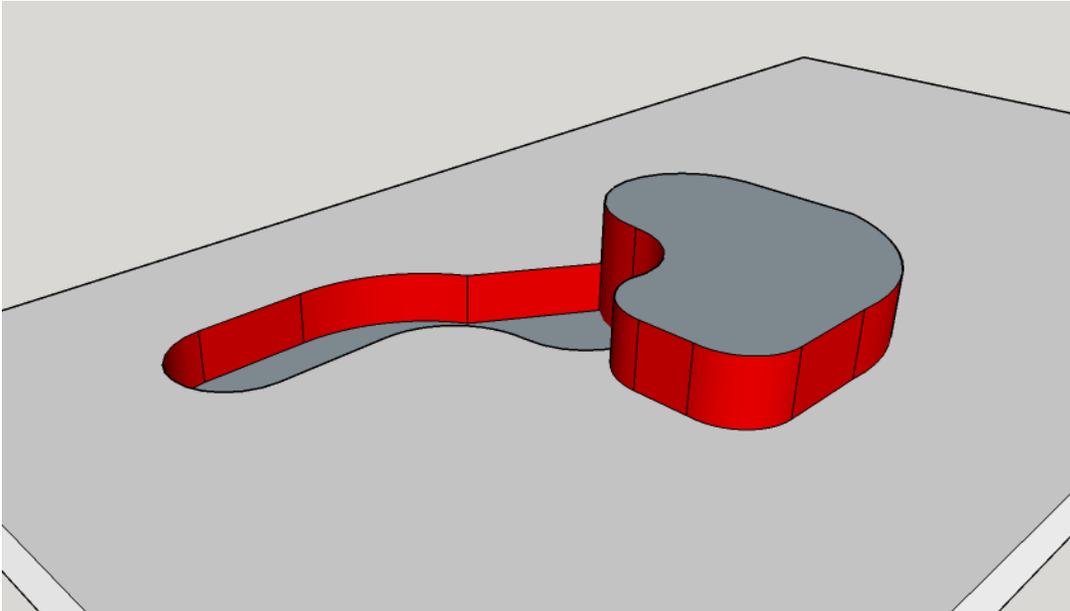
- The rules of a PSC's curved walls all run in the same direction.
- Each planar face of a PSC contains lines that are co-directional with rules of the PSC's curved walls.

PSCs can be internal or external (indicated by the value of the **Location** property in the Geometric Cost Drivers pane).



An internal or external PSC consists of a closed loop of surfaces that can all be side milled from the same setup.

Some PSCs have the value **UNKNOWN** for **Location**, as with the PSC shown in red:



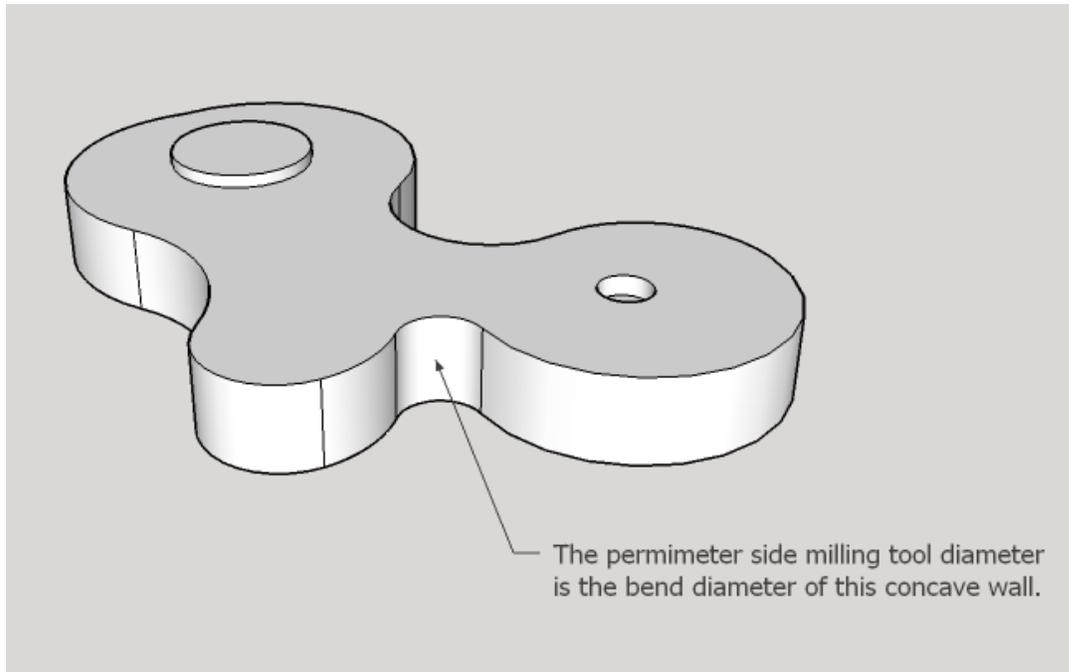
The PSC shown in red has the value **UNKNOWN** for the **Location** property, rather than **INTERNAL** or **EXTERNAL**.

Diameter Selection for Side Milling

Diameter selection for side milling makes use of some special considerations, including whether the surface to be side milled lies on a PSC or height-direction perimeter (see [PSCs and Perimeters](#)). It is often possible (and desirable) for all the surfaces of a perimeter or PSC to be side milled using a single setup and a single tool. In these cases, aPriori chooses a tool diameter as described below.

For surfaces on a perimeter:

- If there is at least one concave curved wall on the perimeter, the tool diameter is the bend diameter of the curved wall with the smallest bend diameter. (See the property **Bend Diameter** in the Geometric Cost Drivers pane.)
- If there is no concave curved wall, the tool diameter is the height of the part's bounding box.



For surfaces on the height-direction perimeter, the tool diameter is the bend diameter of the concave wall with the smallest bend diameter. If there is no concave wall, the part's height is used as the tool diameter.

For surfaces on an external PSC:

- If there is at least one concave curved wall on the perimeter, the tool diameter is the smaller of the following:
 - Bend diameter of the curved wall with the smallest bend diameter. (See the property **Bend Diameter** in the Geometric Cost Drivers pane.)
 - Wall height of the surface with the greatest wall height (See the property **Wall Height** in the Geometric Cost Drivers pane.)
- If there is no concave curved wall, and there is at least one convex curved wall with a value for **Diameter** (see the Geometric Cost Drivers pane), the tool diameter is the smaller of the following:
 - Diameter of the curved wall with the smallest diameter
 - Wall height of the surface with the greatest wall height
- If there is no concave curved wall, and there is no convex curved wall with a value for **Diameter**, the tool diameter is the wall height of the surface with the greatest wall height.

For surfaces on an internal PSC:

- If there is at least one concave curved wall on the perimeter, the tool diameter is the bend diameter of the curved wall with the smallest bend diameter. (See the property **Bend Diameter** in the Geometric Cost Drivers pane.)
- If there is no concave curved wall, the tool diameter is the wall height of the surface with the greatest wall height.

For surfaces on a PSC whose value for **Location** is **UNKNOWN**, the tool diameter is the smallest of the following:

- Wall height in the direction of setup axis

- Bend diameter of the curved wall on the PSC with the smallest bend diameter
- Diameter of the curved wall on the PSC with the smallest diameter

Length to Diameter Ratio Check

For side milling, tool selection checks the ratio of the required tool reach to the selected diameter. (The required tool reach is determined by the part-relative tool orientation selected by feasibility checks—see [Setup Axes and Operation Feasibility](#). This orientation—represented by a setup axis—bears an **Is Accessible From** relation to GCD. The value of the **Length** attribute of this **Is Accessible From** relation is the required tool reach.)

Tool selection fails, if the required tool reach divided by the diameter is greater than the value of the cost model variable **difficultSideMillingLengthToDiameterRatio**.

If the required tool reach divided by the diameter is greater than the value of the setup option **easySideMillingLengthToDiameterRatio**, tool selection is suspended; the cost engine moves on to consideration of other operations and then other GCDs. If the current GCD remains unassigned to an operation after that, tool selection then proceeds with the current diameter, if the node attribute **runFourthCostingPass** is set. Otherwise, tool selection fails.

Tool Series Selection

The selection of the tool series is based on, among others, the following factors:

- Tool diameter
- Required tool reach
- Machine capabilities

Tool series that are alike with regard to the selection criteria are ranked in order of preference in the **Precedence** field of the lookup table **tblSystemToolDeclarations**.

For turning operations, aPiori chooses the highest precedence tool of type **Turning Insert**, as specified in **tblSystemToolDeclarations**.

For threading operations, thread pitch affects tool selection (see [Threading Options](#)).

Tool Type Selection for Pocket Rough Milling

The tool type for each occurrence of the pocket rough milling operation is either **Flat End Mill** or **Ball End Mill**. aPiori automatically selects a tool type as described below. Users can override aPiori's choice with the setup option **Tool Type**—see [Pocket Rough Milling Options](#).

If two diameters are selected for the current pocket (and so there are two occurrences of the roughing operation for this pocket), the tool type for the first occurrence is **Flat End Mill**.

Moreover, if two diameters are selected for the current pocket, the tool type for the second roughing occurrence is **Ball End Mill** if and only if the pocket has one or more of the following:

- Matching wall and bottom fillet diameters
- Non-planar floor
- Walls that form an acute angle with the floor

Finally, if a single diameter is selected for the current pocket, the tool type is **Ball End Mill** if and only if the pocket has one or more of the following (the same three properties listed above):

- Matching wall and bottom fillet diameters
- Non-planar floor
- Walls which form an acute angle with the floor

Tool Type Selection for Standard Slot Milling

Slot Milling uses a flat end mill for slots with flat floors and a ball end mill for slots with semi-circular floors.

Groove Milling uses a keyseat mill if there is a feasible one of the appropriate width; otherwise a groove mill is used if there is a feasible one of the appropriate width.

Rough Milling uses a flat end mill if the slot is open-ended and the tool axis is parallel to the floor. Otherwise, it uses a ball end mill if any of the following hold:

- Slot has a semi-circular floor.
- Slot has a bathtub end.
- Slot is open-ended and has pitch.

Otherwise, Rough Milling uses a flat end mill.

Tool Type Selection for Deburring Operations

By default, tool type depends on GCD type (edge or surface) as well as, for edges, on edge type (internal or external).

By default in starting point VPEs, edge deburring uses the following tools:

- Internal edge deburring: **Wire Tube Brush**
- External edge deburring: **Wire Wheel Brush**

Administrators can customize the defaults with the following cost model variables:

- **defaultInternalEdgeDeburrToolType**
- **defaultExternalEdgeDeburrToolType**

Users can override the default on a per-part basis with the setup option [Default Edge Deburr Tool Type](#).

By default in starting point VPEs, surface deburring uses the **Wire Cup Brush** tool type. Administrators can customize the default with the cost model variable **defaultSurfaceDeburrToolType**. Users can override the default on a per-part basis with the setup option [Default Surface Deburr Tool Type](#).

Note that users can also override the tool type on a per-GCD basis with the setup option [\(Manual Deburr process only\)](#)

If you include Manual Deburr in your routing, the cost model assumes that only edges are deburred, by default. With this setup option, you can override the default, and specify that all surfaces are deburred as well.

Number of Edges

(Individual occurrence of virtual edge deburring only)

By default, for virtual edge deburring, the cost model assumes that a single edge is deburred. With this setup option, you can explicitly specify the number of virtual edges to be deburred.

Deburr Tool Type.

Tool type and material cut code determine the default [Process Material Feed Rate](#), which drives cycle time.

Tool Properties

Tool selection uses interpolation from data tables (which list actual property values for a sampling of individual tools) to derive various tool properties. Tool selection generally derives these properties from the following:

- Tool series
- Tool diameter
- Cut code of the current part's material (see the [VPE Administration Guide](#) for information on cut codes)
- Tool type

Following are some of the data tables used for this purpose:

- **tblMilling**
- **tblDrilling**
- **tblGeneralTurning**

Several other tables are specific to a particular process, such as **tblChamfering** and **tblGunDrilling**.

For surface milling operations, tool selection derives, among others, the following properties (see [Feeds and Speeds in the Machining Cost Model](#)):

- Speed
- Number of tool teeth
- Feed per tooth
- Maximum cut depth (flute height for the solid mill or the insert height for the insert-based mill)

For roughing operations, tool selection derives, among others, the following properties (see [Feeds and Speeds in the Machining Cost Model](#)):

- Speed
- Number of tool teeth
- Feed per tooth
- Axial cut depth
- Radial cut depth

For hole making operations, tool selection derives, among others, the following properties (see [Feeds and Speeds in the Machining Cost Model](#)):

- Speed
- Feed

For turning operations, tool selection derives, among others, the following properties (see [Feeds and Speeds in the Machining Cost Model](#) and [Chipmaking Time for Rough Turning Operations](#)):

- Speed
- Feed
- Cut depth
- Node radius
- Entering angle

For Tapping and Thread Turning, tool selection derives, among others, the following properties (see [Feeds and Speeds in the Machining Cost Model](#) and [Chipmaking Time for Threading Operations](#)):

- Speed
- Thread pitch

For Thread Milling, tool selection derives, among others, the following properties (see [Feeds and Speeds in the Machining Cost Model](#) and [Chipmaking Time for Threading Operations](#)):

- Speed
- Feed
- Thread pitch
- Threads per pass

For some edge treatment operations, such as chamfering and rounding, tool selection derives, among others, the following property:

- Linear speed (that is, tool axis speed—see [Edge Treatment Engagement Time in Cut Time for Machining Operations](#))

For all these types of operations, tool selection also derives these properties, which help to determine [Expendable Tooling Costs](#) and [Process Cycle Time](#):

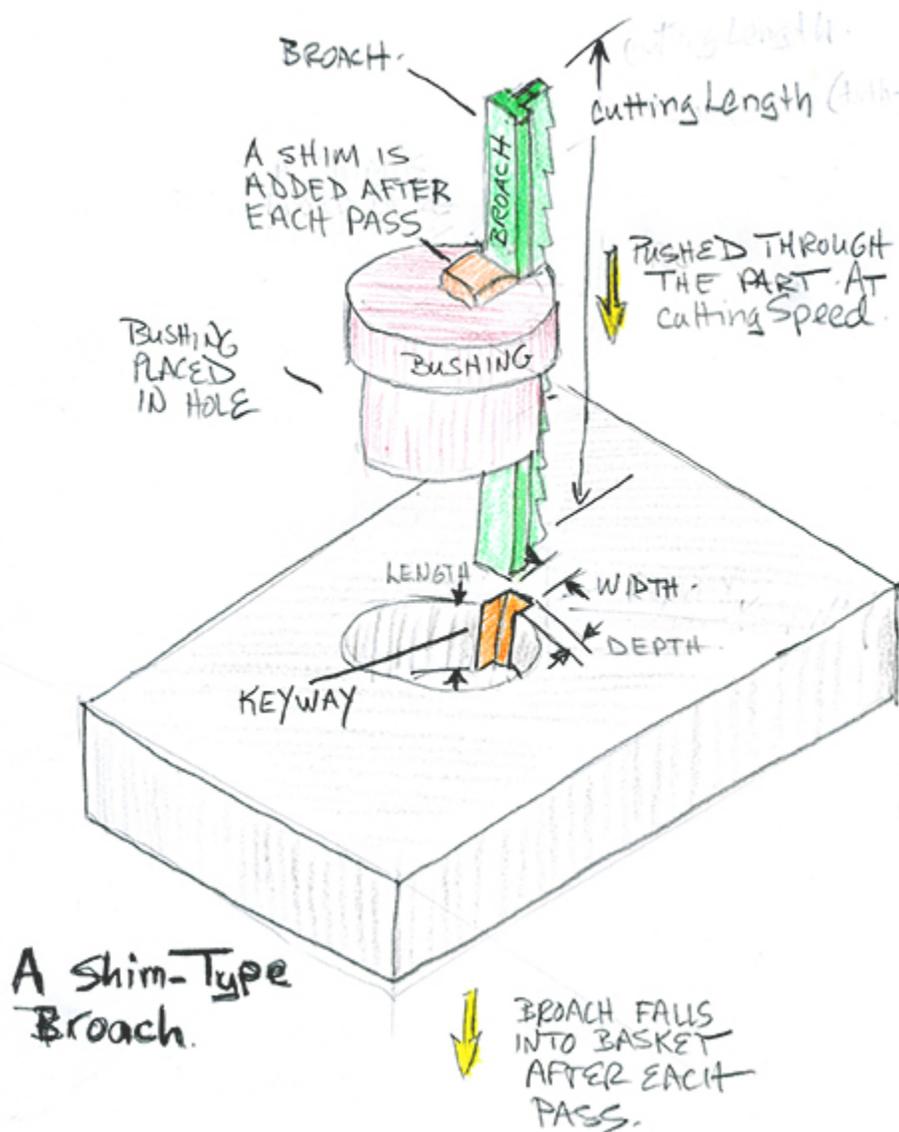
- Tool life
- Tool life cost
- Tool hardness

Tool Selection for Keyway Broaching

After finding the appropriate tool series, tool selection for keyway broaching uses the lookup table **tblPullTypeKeywayBroaching** (for Single Pass Keyway Broaching) or **tblShimTypeKeywayBroaching** (for Multipass Keyway Broaching).

Tool selection first finds tools that are appropriate for the GCD width and the material cut code. From those, tool selection chooses a tool whose maximum recommended keyway length is not exceeded by the GCD length. (If the GCD length is less than the *minimum* recommended keyway length, aPiori assumes that a plate is placed underneath the part to make up for the deficit.)

If the keyway width is too small for all available tools, tool selection picks the smallest-width tool; if the GCD is too wide for all available tools, tool selection picks the largest-width tool.



Based on the values in the lookup table, tool selection for keyway broaching sets the following tool properties:

- Cutting speed: linear cutting speed of the broach in the pull direction
- Teeth: number of teeth on the broach
- Pitch: distance between adjacent teeth
- Feed per tooth: depth of material removed (in the keyway depth direction) per tooth, per pass

Cost Algorithms and Calculations for Machining

This section has the following subsections:

- Feeds and Speeds in the Machining Cost Model
- Operation Cycle Time and Cut Time Calculations
- Chemical Milling Formulas
- Batch Setup Time
- Process Cycle Time
- Expendable Tooling Costs

Feeds and Speeds in the Machining Cost Model

For most machining operations, feed and speed are fundamental to the determination of cutting time.

Feed is the distance the tool travels along or through the part per rotation of the tool (or, for turning operations, per rotation of the workpiece). This is the distance the region of contact moves relative to the workpiece per rotation.

For milling and drilling operations, speed is how fast the tool turns in unit distance per unit time; that is, the speed at which a point on the outer edge of the tool moves along the circular path around the tool's axis of rotation. For turning operations, speed is how fast the workpiece turns in unit distance per unit time; that is, the speed at which a point on the outer edge of the workpiece (at the cut location) moves along the circular path around the turning axis.

This section contains the following subsections:

- Interpolated and User-specified Feed and Speed
- Adjusted Feed and Speed
- Feed, Speed, and Cut Time

Interpolated and User-specified Feed and Speed

When aPriori selects a tool for a machining operation, it establishes default values for feed and speed. The default values are arrived at by interpolation from cost model data tables, based on the following:

- Tool diameter
- Tool series
- material cut code
- For rough material removal, setting for **Rough Material Removal Approach** (see [User Inputs for Machining](#))

Following are some of the data tables used for this purpose:

- **tbIMilling**
- **tbIDrilling**

- **tblGeneralTurning**

Several other tables are specific to a particular process, such as **tblChamfering** and **tblGunDrilling**.

See [Tool Selection for Machining](#) for more information.

Users can override these defaults and specify feed or speed explicitly by using one of a variety of process setup options (see [User Inputs for Machining](#)):

- [Machining Node Process Setup Options](#)
 - **Specify General Milling Speed**
 - **Specify General Turning Speed**
 - **Specify Cutting Speed for Contouring**
 - **Specify Cutting Speed for Facing**
 - **Specify Cutting Speed for Side Milling**
 - **Specify Drilling Speed**
 - **Specify Plunging Speed**
 - **Specify Rough Turning Speed**
- [Surface Finishing Milling Options, Pocket Rough Milling Options, and Bulk Milling Options](#)
 - **Requested Feed per Tooth**
 - **Number of Teeth**
 - **Requested Tool Cutting Speed**

Note that the PSOs for milling operations, instead of specifying feed directly, specify the feed per tooth and the number of teeth: $\text{Feed} = \text{Feed per Tooth} * \text{Number of Tool Teeth}$.

For rough milling and bulk milling, you can also override the use of speed and feed, and specify material removal rate directly.

- [Hole Making Options, Rough Turning Options, and Finish Turning Options](#)
 - **Requested feed per Rev**
 - **Requested Tool Cutting Speed**
- [Threading Options](#)
 - **Requested Tool Cutting Speed**

Adjusted Feed and Speed

aPriori adjusts the interpolated or user-specified feed and speed values based on the following considerations:

- **Machine limitations:** speed is bounded above by the value specified for the machine property **Spindle Speed**. This property specifies the maximum spindle speed achievable by the machine. You can remove this limit with the setup option **Ignore Machine Spindle Speed Limit**.
- **Stock hardness** (or post-heat-treatment material hardness, if applicable for finishing operations—see **General Routing Strategy** and **Material Hardness Achieved Through Heat Treatment** in [Machining Node Process Setup Options](#)). The adjustment uses data from the lookup table **tblHardnessCompensation**.

- Tool length
- Tolerance requirements (see the "Specifying Tolerance and Roughness" section of the aPriori *User Guide*)
- Cost model variable **speedSafetyFactor**
- Cost model variable **powerSafetyFactor**
- For rough milling speed, setting of Rough Milling Aggression Adjustment Dial (see [User Inputs for Machining](#)).

aPriori further adjusts feed by multiplying by one of the following cost model variables:

- **boreFeedAdjustment**
- **drillFeedAdjustment**
- **endmillFeedAdjustment**
- **millFeedAdjustment**
- **turningFeedAdjustment**

aPriori further adjusts speed by multiplying by one of the following cost model variables:

- **boreSpeedAdjustment**
- **drillSpeedAdjustment**
- **endmillSpeedAdjustment**
- **millSpeedAdjustment**
- **turningSpeedAdjustment**

The adjusted values are sometimes referred to (for example, in the Process Options Editor) as *final* feed and *final* speed.

Feed, Speed, and Cut Time

aPriori generally uses the adjusted (final) values for feed and speed as follows in order to determine operation cut time:

- RPM: aPriori uses speed to determine tool RPM. Recall that speed is the speed at which a point on the outer edge of the tool moves along the circular path around the center of the tool. So the distance traveled by the point during one revolution of the tool is:

$$\text{Pi} * \text{Tool Diameter}$$

So the time elapsed during one rotation is:

$$(\text{Pi} * \text{Tool Diameter}) / \text{speed}$$

RPM is the reciprocal of this:

$$\text{RPM} = \text{Speed} / (\text{Pi} * \text{Tool Diameter})$$

Speed is calculated (by aPriori) or specified (by the user) using the units of meters per minute. To calculate RPMs, aPriori converts speed to millimeters per minute, since diameter is calculated or specified in millimeters.

- Tool axis speed: aPriori uses RPM and feed to determine the speed of the tool as it moves along the tool path. Recall that feed is the distance the tool travels along the tool path per tool rotation. So tool axis speed is given by:

Tool Axis Speed = RPM * Feed

See also Tool Axis Speed.

- Area removal rate: for some operations , aPriori uses tool axis speed and contact width to determine area removal rate:

Area Removal Rate = Tool Axis Speed * Contact Width

Contact width is determined using various heuristics, based on tool diameter (or workpiece diameter, for turning), tool reach, and operation type, among other factors.

- Volume removal rate: for some operations, aPriori uses tool axis speed and contact area to determine volume removal rate:

Volume Removal Rate = Tool Axis Speed * Contact Area

Contact area is determined using various heuristics, based on tool diameter (or workpiece diameter, for turning) and cut depth, among other factors.

- Chipmaking time: this is the portion of cutting time during which the tool is engaged and in contact with the workpiece. aPriori usually determines chipmaking time in one of three ways:

- Based on tool path length and tool axis speed:

Chipmaking Time = Tool Path Length / Tool Axis Speed

Most hole-making and hole-finishing operations use this formulation; the tool path length is generally the length of the hole plus the drill-tip length (for blind holes) or twice the drill-tip length (for through holes). In addition, some cases of surface facing use this formulation; aPriori chooses a facing tool path based on tool diameter and surface geometry, as well as on the surface's surrounding geometry.

- Based on GCD area and area removal rate:

Chipmaking Time = GCD Area / Area Removal Rate

Many surface finishing operations use this formulation. Geometry extraction determines the GCD area from the model.

- Based on removed volume and volume removal rate:

Chipmaking Time = Removed Volume / Volume Removal Rate

Bulk milling, rough milling, and rough turning use this formulation. Geometry extraction and material allowance help determine the volume to be removed.

Note that the Process Options editor displays the most recent costing's values for adjusted feed and speed (**Final Feed** and **Final Speed**), as well as tool axis speed (**Linear Axis Feed Rate**) and tool diameter.

Cut time is chipmaking time and non-chipmaking time (during which the tool is engaged but not in contact with the workpiece), together with rapid movement time (during which the tool is not engaged and is approaching or departing a GCD). See [Cut Time for Machining Operations](#) for more information.

Operation Cycle Time and Cut Time Calculations

This section contains the following subsections:

- Cycle Time for Machining Operations
- Cut Time for Machining Operations
- Chipmaking Time for Hole Making and Hole Finishing Operations
- Chipmaking Time for Surface Finishing Milling Operations
- Chipmaking Time for Rough Turning Operations
- Chipmaking Time for Finish Turning Operations
- Chipmaking Time for Finish Dovetail Milling
- Chipmaking Time for Slot Milling
- Chipmaking Time for Groove Milling
- Chipmaking Time for Slot Rough Milling
- Chipmaking Time for Surface Rough Milling
- Chipmaking Time for Pocket Rough Milling
- Chipmaking Time for Bulk Milling
- Chipmaking Time for Threading Operations
- Tool Axis Speed
- Setup Operation Times and Costs

Cycle Time for Machining Operations

The cycle time of individual machining operations is a major contributor to machining process cycle times and costs. For most machining operations, cycle time is the same as cut time:

Cycle Time = Cut Time

See Cut Time for Machining Operations. Exceptions are listed in the following sections:

- Pecking Cycle Time
- Edge Turning Cycle Time
- Keyway Broaching Cycle Time
- Back Counterboring Cycle Time

See also Chemical Milling Formulas.

Cut Time for Machining Operations

Generally, each operation's cut time is calculated with the following formula:

Cut Time = Engagement Time + Rapid Movement Time

Cut time is the sum of the following:

- Engagement time: time during which a tool or part is spinning. See the formula below.
- Rapid movement time: time during which the tool is being positioned while neither tool nor part is spinning. See the formula below.

Engagement Time = Chipmaking Time + Non-chipmaking Time

For most machining operations, engagement time is the sum of the following:

- Chipmaking time: time during which the tool is in contact with the part, and is removing material. See the following sections:
 - Chipmaking Time for Hole Making and Hole Finishing Operations
 - Chipmaking Time for Surface Finishing Milling Operations
 - Chipmaking Time for Rough Turning Operations
 - Chipmaking Time for Finish Turning Operations
 - Chipmaking Time for Finish Dovetail Milling
 - Chipmaking Time for Surface Rough Milling
 - Chipmaking Time for Pocket Rough Milling
 - Chipmaking Time for Bulk Milling
 - Chipmaking Time for Threading Operations
- Non-chipmaking time: time during which the tool is not in contact with the part or removing material, but during which the tool or part is spinning, such as when the tool over-travels the side of the part (see Non-chipmaking Time, below)

Center Drilling Engagement Time = Machine Spotting Time

For center drilling, engagement time is determined by a property of the current machine, **Spotting Time**.

Edge Treatment Engagement Time = (Hole Diameter * Pi) / Tool Linear Speed

For some edge treatment operations, such as edge chamfering and edge rounding, engagement time depends on the following:

- Hole diameter: obtained from geometry extraction, used to calculate edge length.
- Tool linear speed: established by tool selection (see [Tool Properties](#)) or user specified (see [Edge Finishing Option](#)).

Edge Countersinking Engagement Time = Machine Countersinking Time

For edge countersinking, engagement time is determined by a property of the current machine, **Countersinking Time**.

Rapid Movement Time = (Part Length / Rapid Traverse Rate) * Rapid Transfer Distance Factor

Rapid movement time depends on the following:

- Part length: length of the longest side of the part's smallest enclosing rectangle (specified as a GCD property).
- Rapid traversal rate: specified as a machine property.
- Rapid transfer distance factor: specified as the cost model variable **rapidTransferDistanceFactor**.

Non-chipmaking Time

This time is estimated with different heuristics for different operations.

It typically depends on the following:

- Tool axis speed (see [Tool Axis Speed](#))

- Machine property **Approach/Depart Distance**

For rough milling, non-chipmaking time depends on the following:

- Chipmaking time (see [Chipmaking Time for Pocket Rough Milling](#))
- Cost model variable **roughingCutEfficiency** (0.67 in starting point VPEs): this specifies the fraction of engagement time attributable to chipmaking time. Note that engagement time is the time during which the tool is engaged (whether or not it is in contact with the part); it is the sum of chipmaking time and non-chipmaking time (see the [Cut Time for Machining Operations](#)).

For dovetail slot finishing (the Finish Dovetail Milling operation), non-chipmaking time depends on the following:

- Chipmaking time (see [Chipmaking Time for Finish Dovetail Milling](#))
- Cost model variable **finishDovetailMillingCutEfficiency** (0.95 in starting point VPEs): this specifies the fraction of engagement time attributable to chipmaking time. Note that engagement time is the time during which the tool is engaged (whether or not it is in contact with the part); it is the sum of chipmaking time and non-chipmaking time (see the formula above).

Note that, unlike chipmaking time, non-chipmaking time does *not* contribute to expendable tooling costs, another factor in operation costs. Expendable tooling costs depend on tool life and tool life cost (see [Tool Selection](#)) as well as cut time. See [Expendable Tooling Costs](#).

Pecking Cycle Time

Pecking Cycle Time = Cut Time + (Number of Pecks * Peck Lift and Lower Time)

Pecking cycle time depends on the following:

- Cut time: See [Cut Time for Machining Operations](#).
- Number of pecks: total number of pecks performed for the current operation — see the formula below.
- Peck lift and lower time: determined by the value of the cost model variable **peckLiftAndLowerTime**.

Number of Pecks = Amount of Hole to be Pecked / Pecking Depth

Number of pecks is the quotient of the following:

- Amount of hole to be pecked: depth achieved by all the pecks to be performed. By default, this is the length of the GCD (or, if the GCD is part of a multistep hole, length of the multistep hole). (Note that, for holes that are part of a multistep hole, Pecking is always preceded by Center Drilling, which requires that the GCD is the *smallest* hole of the multistep hole.) Users override the default with the option **Amount of Hole to be Pecked**—see [Hole Making Options](#).
- Pecking depth: depth of a single peck. By default, this is the value of the cost model variable **lengthOfPeck**. Users override the default with the option **Peck Depth**—see [Hole Making Options](#).

Edge Turning Cycle Time

Edge Turning Cycle Time = Machine Edge Turning Time

For edge turning, cycle time is determined by a property of the current machine, **Edge Turning Time**.

Keyway Broaching Cycle Time

Keyway Broaching Cycle Time = Handling Time + (Number of Broaching Passes * Cutting Length / Cutting Speed)

Keyway broaching cycle time is the sum of handling time and cutting time:

- Handling time. This is the product of the number of broaching passes (see below) and repositioning time (specified by the PSO **Reposition Time** or by the plant variable **multipassKeywayBroachingPositioningTime** or **singlePassKeywayBroachingPositioningTime**).
- Number of broaching passes. By default, this is specified by the formula below. For Multipass Keyway Broaching, if you specify a value for the PSO **Number of Shims**, number of passes is the number of shims plus 1 (since the first pass doesn't use a shim). For Single Pass Keyway Broaching, you can override the default calculation and specify the number of passes with the PSO **Passes**.
- Cutting length. This is the product of Number of Teeth and Tooth Pitch, both specified by tool properties or PSOs.
- Cutting speed. This is specified by a tool property or the PSO **Cutting Speed**. If the tool property exceeds the product of the machine property **Max Cutting Speed** and the plant variable **speedSafetyFactor**, it is adjusted downward to the product of **Max Cutting Speed** and **speedSafetyFactor**.

Number of Broaching Passes = Keyway Depth / Depth per Pass

Number of broaching passes is the quotient of the following:

- Keyway depth (specified by geometry extraction)
- Depth per pass. This is the product of Feed per Tooth and Number of Teeth, both specified by tool properties or PSOs.

Back Counterboring Cycle Time

Back Counterboring Cycle Time = Cut Time + Tool Change Time + Tool Centering Time

Back counterboring cycle time depends on the following:

- Cut time: See [Cut Time for Machining Operations](#).
- Tool change time. This is specified by the cost model variable **counterBoringToolChangeTime** (1 minute in starting point VPEs). It includes time to assemble and disassemble the tool.
- Tool centering time: This is specified by the cost model variable **drillPressToolCenterTime** (10 seconds in starting point VPEs). It includes time to center the tool after it has been assembled.

Note that use of a manually-assembled, multi-piece counterboring tool is assumed. See [Back Counterboring](#) for more information.

Chipmaking Time for Hole Making and Hole Finishing Operations

Most hole making and hole finishing operations use the following formula:

Chipmaking Time = Tool Path Length / Tool Axis Speed

For most hole making and hole finishing operations, chipmaking time depends roughly on the following:

- Tool path length: distance the tool travels through the part during the operation. This is typically the length of the hole plus the drill-tip length (for blind holes) or twice the drill-tip length (for through holes).
- Tool axis speed: rate at which the tool travels through the part. See [Tool Axis Speed](#).

Note that for center drilling, and edge treatment operations, engagement time is not divided into chipmaking and non-chipmaking time—see [Cut Time for Machining Operations](#).

Note also that chipmaking time for Pecking does not include peck lift and lower time—see [Cycle Time for Machining Operations](#).

Chipmaking Time for Surface Finishing Milling Operations

The formula for milling chip-making time varies from operation to operation. Many surface finishing operations use a formula roughly like this:

Chipmaking Time = Number of Passes * (Surface Area / Area Removal Rate)

For most finishing operations, chip-making time depends roughly on the following:

- Number of passes: number of times the tool passes over the entire surface. By default, aPriori determines this based on required tolerance and the lookup table [tblGtolProcessCapabilities](#); the default value is typically 1 in aPriori starting point VPEs. Users can specify a value with the setup option **Number of Finishing Passes**—see [Surface Finishing Milling Options](#). If the setup option does not exist for the current operation, this value is typically 1.
- Surface area: current GCD's surface area (specified as a GCD property). For the Base Plate Facing operation (used in some Additive Manufacturing routings, and performed on the BuildDirection GCD), this is the area of the base plate, which is the product of the machine bed length and width.
- Removal rate: rate at which material is removed from the surface, in unit area per unit time. See the formula below.

The formula for facing varies with the assumed tool path. Some cases of facing involve just the GCD perimeter; formulas for these cases use tool path length and tool axis speed rather than area and area-removal rate.

Chipmaking Time = Number of Passes * (Tool Path Length / Tool Axis Speed)

For some facing operations, chipmaking time depends roughly on the following:

- Number of passes: number of times the tool passes over the entire surface. By default, aPriori calculates this based on required tolerance; the computed value is typically 1 in aPriori starting point VPEs. Users can specify a value with the setup option **Number of Finishing Passes**—see [Surface Finishing Milling Options](#). If the setup option does not exist for the current operation, this value is typically 1.

- Tool path length: distance the tool travels along the part's surface during one pass.
- Tool axis speed: rate at which the tool travels along the surface of the part. See [Tool Axis Speed](#).

Area Removal Rate = Contact Width * Tool Axis Speed

Area removal rate is the product of the following:

- Contact width: the length (in units of distance), perpendicular to the direction of motion of the tool along the part's surface, of the contact between the tool and the GCD. This is calculated based on a number of factors, including tool diameter (see [Tool Selection](#)), and in some cases data in the lookup table **tblToolReachCompensation**. It is often half the tool diameter.
- Tool axis speed: speed of the tool along the part's surface. See [Tool Axis Speed](#).

Chipmaking Time for Rough Turning Operations

Rough turning operations use the formulas below.

Chipmaking Time = Volume / Volume Removal Rate

Chipmaking time is the quotient of the following:

- Volume: GCD volume (for rings) or the product of surface area (obtained by geometry extraction) and roughing depth (as specified by the cost model variable **finishAllowance** or the option **Casting Depth**—see [Rough Turning Options](#)).
- Volume removal rate: rate at which material is removed from the part. See the formula below.

Volume Removal Rate = Contact Area * Tool Axis Speed

Volume removal rate is the product of the following:

- Contact Area: area of the region of contact between the tool's cutting edge and the workpiece during one rotation of the workpiece. See the formula below.
- Tool axis speed: speed at which the tool moves along the workpiece in the direction along which the turning axis runs. See [Tool Axis Speed](#).

Contact Area = Cut Depth * Part Diameter * Pi

For rough turning operations, the contact area is estimated as the product of the following:

- Cut depth: depth of the cut as determined by tool selection (see [Tool Properties](#)) or the process setup option **Requested Cut Depth** (see [Rough Turning Options](#)). This value is adjusted based on machine power and limited by material allowance (as specified by the cost model variable **finishAllowance** or the option **Casting Depth**—see [Rough Turning Options](#)).
- Part diameter * Pi: workpiece circumference at the cut location.

Note that

$$\begin{aligned} \text{Volume Removal Rate} &= (\text{Cut Depth} * \text{Part Diameter} * \text{Pi}) * \text{Tool Axis Speed} \\ &= (\text{Cut Depth} * \text{Part Diameter} * \text{Pi}) * \text{Feed} * \text{RPM} \\ &= (\text{Cut Depth} * \text{Part Diameter} * \text{Pi}) * \text{Feed} * (\text{Speed} / (\text{Part Diameter} * \text{Pi})) \end{aligned}$$

$$= \text{Cut Depth} * \text{Feed} * \text{Speed}$$

Chipmaking Time for Finish Turning Operations

Finish turning operations use the formulas below.

Chipmaking Time = Number of Passes * Area / Area Removal Rate

Chipmaking time is the quotient of the following:

- Number of passes: number of times the tool passes over the surface of the GCD. By default, aPiori calculates this based on required tolerance and the lookup table **tblGtolProcessCapabilities**; the default value is typically 1 in aPiori starting point VPEs. Users can specify a value with the setup option **Number of Finishing Passes**—see [Surface Finishing Milling Options](#).
- Area: sweep area of the nearest Is About relation nearest to the GCD, obtained from geometry extraction.
- Area removal rate: see the formula below.

Area Removal Rate = Contact Width * Tool Axis Speed

Area removal rate is the product of the following:

- Contact width: width of the line of contact between the tool and the workpiece. This is the workpiece circumference at the cut location, that is, the part diameter times Pi.
- Tool axis speed: speed at which the tool advances in the direction parallel to the turning axis. See [Tool Axis Speed](#).

Note that

$$\begin{aligned} \text{Area Removal Rate} &= (\text{Part Diameter} * \text{Pi}) * \text{Tool Axis Speed} \\ &= (\text{Part Diameter} * \text{Pi}) * \text{Feed} * \text{RPM} \\ &= (\text{Part Diameter} * \text{Pi}) * \text{Feed} * (\text{Speed} / (\text{Part Diameter} * \text{Pi})) \\ &= \text{Feed} * \text{Speed} \end{aligned}$$

Note that for Edge Turning, cycle time is determined by a property of the current machine, **Edge Turning Time**—see [Cycle Time for Machining Operations](#).

Chipmaking Time for Finish Dovetail Milling

Finish Dovetail Milling uses the formula below:

Chipmaking Time = (Slot Length / Tool Axis Speed) * Total Number of Passes

For dovetail slot finishing, chipmaking time depends on the following:

- Slot length: specified by the geometric property **Length**.
- Tool axis speed: rate at which the tool travels along the length of the slot. See [Tool Axis Speed](#).
- Total number of passes: this is twice the number of passes required per side. The number of passes required per side is determined using a heuristic derived from a large, representative data sample. The heuristic represents the number of passes as a linear combination of tool neck diameter and slot depth (GCD property **Dovetail Depth A**). See also [Diameter Selection for Dovetail Slot Finishing](#).

Note that, in some cases, the tool has been chosen on the basis of the assumption that it will cut both sides of the slot at once during the first pass. This allows selection of a larger, higher feed, tool (see [Diameter Selection for Dovetail Slot Finishing](#)). In practice, cutting both sides at once in the first pass requires reducing the first-pass feed rate. But this formula assumes the same feed rate for all passes, and accounts for the in-practice feed rate reduction by including an extra pass. Therefore the formula uses the same number of passes regardless of the assumption underlying tool selection.

Chipmaking Time for Slot Milling

Slot Milling uses the formula below:

$$\text{Chipmaking Time} = (\text{Slot Length or Depth} / \text{Tool Axis Speed}) * \text{Total Number of Passes}$$

For Slot Milling, chipmaking time depends on the following:

- Slot length or depth: if the tool axis is parallel to the slot floor (see [Standard Slot Operations](#)), this is specified by the larger of the geometric properties **Depth A** and **Depth B**. Otherwise, this is the sum of the geometric properties **End1 Length**, **Length**, and **End2 Length**.
- Tool axis speed: rate at which the tool travels along the length or depth of the slot. This is determined as described in Tool Axis Speed.
- Total number of passes: by default, the number of passes is determined as follows:
 - If the tool axis is parallel to the slot floor (see [Standard Slot Operations](#)), the number of passes is the sum of the geometric properties **End1 Length**, **Length**, and **End2 Length** divided by the axial cut depth (see [Axial Cut Depth](#)), rounded up to the nearest integer.
 - Otherwise, the number of passes is the larger of the geometric properties **Depth A** and **Depth B** divided by the axial cut depth (see [Axial Cut Depth](#)), rounded up to the nearest integer. Users can specify the number of passes with the setup option [Requested Number of Axial Passes](#).

Chipmaking Time for Groove Milling

Groove Milling uses the formula below:

$$\text{Chipmaking Time} = (\text{Slot Length} / \text{Tool Axis Speed}) * \text{Total Number Axial of Passes} * \text{Number of Radial Passes}$$

For Groove Milling, chipmaking time depends on the following:

- Slot length: this is generally the sum of the following geometric properties of the slot:
 - **End1 Length**
 - **Length**
 - **End2 Length**.

For fully open slots and loop slots (that is, if **End1Type** and **End2Type** are both **OPEN** or are both **LOOP**), this is the sum of the slot **Length** and half the tool diameter.

- Tool axis speed: rate at which the tool travels along the length of the slot. This is determined as described in Tool Axis Speed.

- Number of axial passes: by default, the number of axial passes is the slot width (the value of the geometric property **Width**) divided by the tool width (see [Requested Tool Width](#)), rounded up to the nearest integer. Users can override the default with the setup option [Requested Number of Axial Passes](#).
- Number of radial passes: by default, the number of radial passes is the slot depth (the larger of the geometric properties **Depth A** and **Depth B**) divided by the radial cut depth (generally 50% of tool width—see [Radial Cut Depth](#)), rounded up to the nearest integer. Users can specify the number of passes with the setup option [Requested Number of Radial Passes](#).

Chipmaking Time for Slot Rough Milling

The Rough Milling operation for Slot GCDs uses the formulas below:

Chipmaking Time = Volume / Volume Removal Rate

Chipmaking time is the quotient of the following:

- Volume: slot volume as determined by geometry extraction.
- Volume removal rate: rate at which material is removed from the workpiece. The default rate is calculated as described in the formula below. Users can specify a volume removal rate with the setup option [Material Removal Rate](#).

Volume Removal Rate = Contact Area * Tool Axis Speed

Volume removal rate is the product of the following:

- Contact Area: Area of the region of contact between the tool and the workpiece. See the formula below.
- Tool axis speed: rate at which the tool advances against the workpiece. See [Tool Axis Speed](#).

Contact Area = Engagement Length * Cut Depth

Contact area is the product of the following:

- Engagement length: length, in the radial direction, of the region of contact between the tool and the workpiece. This is typically half the tool diameter (see [Radial Cut Depth](#)).
- Cut depth: depth of the cut in the axial direction (see [Axial Cut Depth](#)). This value is adjusted based on machine power, and limited (if not specified by setup option) by the tool's maximum cutting depth and by slot depth.

Chipmaking Time for Surface Rough Milling

Rough Milling uses the formulas below.

Chipmaking Time = Volume / Volume Removal Rate

Chipmaking time is the quotient of the following:

- Volume: GCD volume, the product of surface area (obtained by geometry extraction) and roughing depth (as specified by the cost model variable **finishAllowance** or the option [Roughing Depth](#)—see [Pocket Rough Milling Options](#)).
- Volume removal rate: rate at which material is removed from the workpiece. The default rate is calculated as described in the formula below. Users can specify a

volume removal rate with the setup option **Material Removal Rate** (see [Pocket Rough Milling Options](#)).

Volume Removal Rate = Contact Area * Tool Axis Speed

Volume removal rate is the product of the following:

- Contact Area: Area of the region of contact between the tool and the workpiece. See the formula below.
- Tool axis speed: rate at which the tool advances against the workpiece. See [Tool Axis Speed](#).

Contact Area = Engagement Width * Cut Depth

Contact area is the product of the following:

- Engagement width: width of the region of contact between the tool and the workpiece. This is typically half the tool diameter by default, but can be specified with the process setup option **Radial Cut Depth**—see [Pocket Rough Milling Options](#).
- Cut depth: depth of the cut as determined by tool selection (see [Tool Selection for Machining](#)) or the process setup option **Axial Cut Depth** (see [Pocket Rough Milling Options](#)). This value is adjusted based on machine power and limited by material allowance (as specified by the option **Casting Depth**—see [Pocket Rough Milling Options](#)).

Chipmaking Time for Pocket Rough Milling

Rough Milling uses the formulas below.

Chipmaking Time = Volume / Volume Removal Rate

Chipmaking time is the quotient of the following:

- Volume: this is the volume removed by the current instance of the Rough Milling operation for the current GCD.

If there is only one such instance, the volume removed is the pocket's volume as determined by geometry extraction.

If there are two such instances, and the current instance is the first instance (the instance that uses the larger tool diameter), the volume removed by the current instance is interpolated based on the following assumptions:

- There is a linear relationship between the tool diameter and the volume removed.
- The value of the geometric property **Inside Diameter Tool Volume** specifies the volume that would be removed by a tool whose diameter is equal to the value of the geometric property **Inside Diameter**.
- The pocket's total volume would be removed by a tool whose diameter is equal to the value of the geometric property **Corner Diameter**.

If there are two instances of the roughing operation for the current pocket, and the current instance is the second instance (the one that uses the smaller tool diameter), the volume removed is the difference between the pocket's total volume and the volume removed by the operation's first instance.

For a given instance of the roughing operation, users can override the volume removed with the setup option **Requested Percent Milled**—see [Pocket Rough Milling Options](#).

- Volume removal rate: rate at which material is removed from the workpiece. The default rate is calculated as described in the formula below. Users can specify a volume removal rate with the setup option **Material Removal Rate** (see [Pocket Rough Milling Options](#)).

Volume Removal Rate = Contact Area * Tool Axis Speed

Volume removal rate is the product of the following:

- Contact Area: Area of the region of contact between the tool and the workpiece. See the formula below.
- Tool axis speed: rate at which the tool advances against the workpiece. See [Tool Axis Speed](#).

Contact Area = Engagement Width * Cut Depth

Contact area is the product of the following:

- Engagement width: width of the region of contact between the tool and the workpiece. This is typically half the tool diameter by default, but can be specified with the process setup option **Radial Cut Depth**—see [Pocket Rough Milling Options](#).
- Cut depth: depth of the cut as determined by tool selection (see [Tool Selection for Machining](#)) or the process setup option **Axial Cut Depth** (see [Pocket Rough Milling Options](#)). This value is adjusted based on machine power, and limited (if not specified by setup option) by the tool's maximum cutting depth and by pocket depth.

Chipmaking Time for Bulk Milling

Bulk Milling uses the formulas below.

Chipmaking Time = Volume / Volume Removal Rate

Chipmaking time is the quotient of the following:

- Volume: volume to be removed by bulk milling. By default, aPiori calculates this volume based on the geometric characteristics of the part, as well on the number of different tool diameters selected for bulk milling operations. You can use the setup option **Requested Percent Milled** (see [Bulk Milling Options](#)) to specify the percent of part volume to be removed by the designated individual bulk milling operation. If you specify a nonzero value for **Dropoff Volume** (see [Bulk Milling Options](#)), the volume to be removed is less than or equal to the difference between part volume and dropoff volume. **Requested Percent Milled** specifies the volume to be removed as a percentage of the difference between part volume and dropoff volume.
- Volume removal rate: rate at which material is removed from the workpiece. The default rate is calculated as described in the formula below. Users can specify a volume removal rate with the setup option **Material Removal Rate** (see [Bulk Milling Options](#)).

Volume Removal Rate = Contact Area * Tool Axis Speed

Volume removal rate is the product of the following:

- Contact Area: Area of the region of contact between the tool and the workpiece. See the formula below.
- Tool axis speed: rate at which the tool advances against the workpiece. See [Tool Axis Speed](#).

Contact Area = Engagement Width * Cut Depth

Contact area is the product of the following:

- Engagement width: width of the region of contact between the tool and the workpiece. The percentage of the tool diameter specified by the setup option Radial Cut Depth (see [Bulk Milling Options](#)). If no radial cut depth is specified, the width defaults to 50% of the tool diameter.
- Cut depth: The percentage of the tool diameter specified by the setup option Axial Cut Depth (see [Bulk Milling Options](#)). If no axial cut depth is specified, the width defaults to 50% of the tool diameter. This value is adjusted based on workpiece material and machine power.

Chipmaking Time for Threading Operations

Tapping, Thread Turning, and Thread Milling use the following formula:

Chipmaking Time = Tool Path Length / Tool Axis Speed

For Tapping and Thread Turning, chipmaking time depends roughly on the following:

- Tool path length: distance the tool travels along the tool's axis of rotation. For Tapping and Thread Turning, this is twice the length of the threaded portion of the hole, if specified in the model; or twice the length of the hole, if not specified. For Thread Milling, it is the GCD circumference times the number of passes (calculated from threaded length, pitch, and threads per pass).
- Tool axis speed: rate at which the tool travels through the part. See the formula below.

Tool Axis Speed = Thread Pitch * RPM

Tool axis speed is the product of the following:

- Thread pitch: distance between threads. This is specified by the operation-level process setup options **Thread Pitch** and **Thread Units**. (see [Threading Options](#)) If the user specifies threads per inch (instead of millimeters per thread), aPriori converts the value to millimeters per thread. If the user does not specify a thread pitch, the default of 1 millimeter is used. This value is equal to the tool feed, since it is the distance the tool travels through the hole during one rotation of the tool.
- RPM: number of times the tool rotates per minute. See the formula for RPM in [Tool Axis Speed](#).

Tool Axis Speed

Tool axis speed, the speed at which the tool travels along or through the part, contributes to removal rates and chipmaking time.

Tool Axis Speed = Feed * RPM

Tool axis speed is the product of the following:

- Feed: distance the tool travels along or through the part per rotation of the tool. An initial value for feed is generally based on one or more of the following:
 - Tool selection's value for feed or feed per tooth—see [Tool Selection](#).
 - Tool selection's value for number of teeth—see [Tool Selection](#).
 - Various setup options—see [Interpolated and User-specified Feed and Speed](#).

The value is adjusted to compensate for various factors, including tool reach and required tolerance.

The value is also adjusted by multiplying by one of the following cost model variables:

- **boreFeedAdjustment**
- **drillFeedAdjustment**
- **endmillFeedAdjustment**
- **millFeedAdjustment**
- **turningFeedAdjustment**

See [Feeds and Speeds in the Machining Cost Model](#).

- RPM: number of times the tool rotates per minute. See the formula below.

RPM = Speed / (Pi * Tool Diameter)

RPMs, the number of times the tool rotates per minute, depends on the following:

- Speed: How fast the tool or workpiece turns in unit distance per unit time; that is, the speed at which a point on the outer edge of the tool moves along the circular path around the center of the tool or (for turning) the speed at which .

Tool selection establishes an initial value—see [Tool Selection](#). Users can override this value with a setup option—see [Interpolated and User-specified Feed and Speed](#). The value is then adjusted to compensate for various factors, including machine spindle speed limitations and stock hardness.

The value is also adjusted by multiplying by one of the following cost model variables:

- **boreSpeedAdjustment**
- **drillSpeedAdjustment**
- **endmillSpeedAdjustment**
- **millSpeedAdjustment**
- **turningSpeedAdjustment**

See [Feeds and Speeds in the Machining Cost Model](#).

- Tool diameter: Specified as tool property, established by tool selection. Users can override this value with process setup options. See [Tool Selection](#).

Speed is calculated (by aPriori) or specified (by the user) using the units meters per minute. To calculate RPMs, aPriori converts speed to millimeters per minute, since diameter is calculated or specified in millimeters.

Note therefore that, given these units, some formulas use the following:

$$\begin{aligned} \text{RPM} &= 1000 * \text{Speed} / (\text{Pi} * \text{Diameter}) \\ &= (1000 / \text{Pi}) * \text{Speed} / \text{Diameter} \\ &=_{\text{approx}} 318 * \text{Speed} / \text{Diameter} \end{aligned}$$

Setup Operation Times and Costs

aPriori supports several approaches for determining part setup times and the corresponding part setup costs. Which method is used depends on the following:

- Value of the machine property **Offline Load Capable** for the current machine
- Value of the cost model variable **partSetupTimeMethod**

Following are the different approaches to determining part setup times:

- One approach is for machines with automated part changeover capabilities (specifically for machining centers that support offline loading and incorporate the use of automated pallet change mechanisms). For the 3-, 4-, and 5-axis mill machine types, if the machine property **Offline Load Capable** is **true**, the addition to cycle time for the switching of parts between operations is based on the value of the property **Base Part Setup Time**, which represents the machine-specific pallet change time. The addition to per-part cycle time is this value divided by the number of parts in the pallet. In this case, you may wish to decrease the values of the machine properties **Number of Operators** and/or **Labor Time Standard**, to reflect that part loading is occurring in parallel with machining and that the automated changeover systems require reduced operator attention.
- Another approach is best suited for manufacturing environments in which part setup is performed as quickly as possible and the time allotted simply varies by part weight. By default in starting point VPEs, for machines *without* automated changeover capabilities (that is, if the machine property **Offline Load Capable** is **false**), aPriori uses a weight-based approach. In this case, the per-part setup time is a linear function of the product of the following two values:
 - Handling time per operator
 - Number of handling operators (note that this is different from the machine property **Number of Operators**)

The linear function's coefficient is **partSetupTimeAdjustmentFactor** (1 in starting point VPEs), and the constant is **extraSetupTime** (0 in starting point VPEs).

Number of handling operators is looked up by weight in the lookup table **tblHandlingTimes**. Handling time per operator is interpolated from values looked up by part weight in **tblHandlingTimes**.

Equipment	Handling Time (s)	Max Weight (kg)	Num Operators
crane	1,800.00	2,000.00	2.00
crane	2,700.00	9,999,999.00	2.00
forklift	540.00	300.00	1.00
forklift	900.00	500.00	1.00
none	1.00	0.00	1.00
none	2.00	1.00	1.00
none	10.00	5.00	1.00
none	30.00	15.00	1.00
none	45.00	20.00	1.00

The interpolated value is based on the table rows whose **Max Weight** values straddle the mass that must be handled. If the mass falls below the minimum mass listed in the table, the handling time is considered negligible, and is set to 0. If the mass exceeds the maximum mass listed in the table, aPiori uses the values in the row with the maximum mass.

- An alternate, machine-based approach is suited for lower-volume precision-machining environments, in which a great deal of time and care is taken with each part setup to minimize errors and scrap. If the machine property **Offline Load Capable** is false and the cost model variable **partSetupTimeMethod** is **machineBased**, aPiori uses the slower, more expensive machine-based approach. In this case, the per-part setup time is a linear function of the value of the machine property **Base Part Setup Time**. The function's coefficient is **partSetupTimeAdjustmentFactor** (1 in starting point VPEs), and the constant is **extraSetupTime** (0 in starting point VPEs).

See also [Working with Part Setups and SetupAxis GCDs](#).

For Jig Boring and Jig Grinding, part setup times based on positional tolerance. The time is based on linear interpolation; it falls somewhere between the values of the cost model variables **jigBoreMaxPartSetupTime** and **jigBoreMinPartSetupTime**, depending on where part's tightest required tolerance falls between the cost model variables **jigBoreMinPosTol** and **jigBoreMaxPosTol**.

Chemical Milling Formulas

This section covers formulas associated with the following processes and their operations:

- Bench Operation Formulas
- Mask Spray Formulas
- Mask Cure Formulas
- Scribe Formulas
- Etch Cell Formulas
- DeMask Formulas

Bench Operation Formulas

The Bench Operation process models a number of different operations that are performed at a bench work area (see [Machine Selection for Bench Operation](#)). The process has one child operation for each such operation: Cleaning, Final Inspection, Identing, Line Sealing, and Spark Testing.

Process-level formulas are listed below, followed by operation-level formulas.

Cycle Time = Process Time * Adjustment Factor

Cycle time is the product of the following:

- Process time (see formula below)
- Adjustment factor (specified by the cost model variable **cycleTimeAdjustmentFactor**). This factor is 1 in aPriori starting point VPEs. VPE administrators can modify **cycleTimeAdjustmentFactor** in order to adjust cycle times across processes within the current VPE.

Process Time = Operations Time + Handling Time

Process time depends on the following:

- Operations time: this is the sum of the cycle times of the child operations. See formulas below.
- Handling time (see formula)

Handling Time = Load Time + Unload Time

Handling time is the sum of the following:

- Load time (see formula)
- Unload time (see formula)

Load Time = Number of Handling Operators * Handling Time per Operator

Load Time is the product of the following:

- Number of handling operators: this is looked up by weight in the lookup table **tblHandlingTimes**. Part weight is material density times part volume (blank area times blank thickness).
- Handling time per operator: this is interpolated from values looked up by part weight in **tblHandlingTimes**. Part weight is material density times part volume (blank area times blank thickness).

Unload Time = Number of Handling Operators * Handling Time per Operator

Unload Time is the product of the following:

- Number of handling operators: this is looked up by weight in the lookup table **tblHandlingTimes**. Part weight is material density times part volume (blank area times blank thickness).
- Handling time per operator: this is interpolated from values looked up by part weight in **tblHandlingTimes**. Part weight is material density times part volume (blank area times blank thickness).

Expendable Tooling Cost Per Part

This is the sum of the consumable materials costs for the child operations. See the formulas below.

Cleaning Operation Cycle Time = Part Surface Area / Cleaning Rate

Cycle time for the Cleaning operation depends on the following:

- Part surface area (specified by a geometry property)
- Cleaning rate: this is looked up by the flattened part's projected area in the lookup table **tblChemicalMilling**.

Component Area (mm ²)	Manual Clean Rate (mm ² / s)	Peel Rate (mm ² / s)
1,000,000.00	50,000.00	4,166.00
5,000,000.00	35,000.00	4,166.00
50,000,000.00	20,000.00	4,166.00

Cleaning Operation Consumable Materials Cost = Cleaning Wipes Quantity * Cleaning Wipes Cost Each

The cost model for the Cleaning operation assumes the use of Diestone SR (PF-SR) Wipes. Consumable materials cost is the product of the following:

- Cleaning wipes quantity: the cost model assumes the use of at least one wipe, and one wipe per square meter of the blank's surface area.
- Cleaning wipes cost each: this is specified by the tool shop variable **consumableMaterial_Diestone_SR_Wipes**.

Final Inspecting Operation Cycle Time

Cycle time for the Final Inspecting operation is the time for the final, visual inspection of the part. By default, it is specified by the cost model variable **defaultFinalInspectionTime** (5 minutes in starting point VPEs). Users can override the default on a part-by-part basis with the setup option Final Inspection Time—see [Bench Operation Options](#).

Identing Operation Cycle Time

Cycle time for the Identing operation is the time to vibro etch an identifier onto the part. By default, it is specified by the cost model variable **defaultIdentingTime** (45 seconds in starting point VPEs). Users can override the default on a part-by-part basis with the setup option Identing Time—see [Bench Operation Options](#).

Spark Testing Operation Cycle Time

Cycle time for the Spark Testing operation is specified, by default, by the cost model variable **defaultSparkTestTime** (2 minutes in starting point VPEs). Users can override the default on a part-by-part basis with the setup option Spark Test Time—see [Bench Operation Options](#).

Blank Line Sealing Operations

Cycle Time = Part Surface Area / Line Sealing Roller Rate

Cycle time for the Line Sealing operation performed on the Blank GCD depends on the following:

- Part surface area (specified by a geometry property)
- Line sealing roller rate: by default, this is specified by the cost model variable **lineSealingRollerRate** (92903 mm²/sec in starting point VPEs).

Consumable Materials Cost = Line Sealer Quantity * Line Sealer Cost Per Liter

Consumable materials cost for the Line Sealing operation performed on the Blank GCD is the product of the following:

- Line sealer quantity: the cost model assumes two coats of line sealant, where each coat uses 0.91 liters per square meter of part surface area.
- Line sealer cost per liter: this is specified by the toolshop variable `consumableMaterial_LineSealer_JW533Red`.

Curved Surface, Curved Wall, Form, and Planar Face Line Sealing Operations**Cycle Time = GCD Perimeter / Line Sealing Brush Rate**

Cycle time for the Line Sealing operation performed on surfaces of individual pockets (Form GCDs) depends on the following:

- GCD perimeter (specified by a geometry property)
- Line sealing brush rate: by default, this is specified by the cost model variable `lineSealingBrushRate` (20 mm/sec in starting point VPEs).

Consumable Materials Cost = Line Sealer Quantity * Line Sealer Cost Per Liter

Consumable materials cost for the Line Sealing operation performed on surfaces of individual pockets (Form GCDs) is the product of the following:

- Line sealer quantity: the cost model assumes two coats of line sealer, where each coat uses 0.91 liters per square meter of surface area sealed. The surface area sealed is the GCD perimeter times an assumed brush width of 1 inch.
- Line sealer cost per liter: this is specified by the toolshop variable `consumableMaterial_LineSealer_JW533Red`.

Mask Spray Formulas

See [Mask Spray Formulas](#) in the Surface Treatment chapter of this Guide.

Mask Cure Formulas**Cycle Time = Process Time * Adjustment Factor**

Cycle time is the product of the following:

- Process time (see formula below)
- Adjustment factor (specified by the cost model variable `cycleTimeAdjustmentFactor`). This factor is 1 in aPiori starting point VPEs. VPE administrators can modify `cycleTimeAdjustmentFactor` in order to adjust cycle times across processes within the current VPE.

Process Time = Operations Time + Handling Time

Process time depends on the following:

- Operations time: operation cycle time (cure time) is looked up in the lookup table `tblMaskingMaterials`.

By default, masking material is specified by the table's first entry. Users can override the default on a part-by-part basis with the setup option **Select maskant material used**.—see [Mask Cure Options](#).

- Handling time (see formula)

Handling Time = Load Time + Unload Time

Handling time is the sum of the following:

- Load time (see formula)
- Unload time (see formula)

Load Time = Number of Handling Operators * Handling Time per Operator

Load Time is the product of the following:

- Number of handling operators: this is looked up by weight in the lookup table **tblHandlingTimes**. Part weight is material density times part volume (blank area times blank thickness).
- Handling time per operator: this is interpolated from values looked up by part weight in **tblHandlingTimes**. Part weight is material density times part volume (blank area times blank thickness).

Unload Time = Number of Handling Operators * Handling Time per Operator

Unload Time is the product of the following:

- Number of handling operators: this is looked up by weight in the lookup table **tblHandlingTimes**. Part weight is material density times part volume (blank area times blank thickness).
- Handling time per operator: this is interpolated from values looked up by part weight in **tblHandlingTimes**. Part weight is material density times part volume (blank area times blank thickness).

Scribe Formulas**Cycle Time = Process Time * Adjustment Factor**

Cycle time is the product of the following:

- Process time (see formula below)
- Adjustment factor (specified by the cost model variable **cycleTimeAdjustmentFactor**). This factor is 1 in aPriori starting point VPEs. VPE administrators can modify **cycleTimeAdjustmentFactor** in order to adjust cycle times across processes within the current VPE.

Process Time = Pocket Scribing Time + Rapid Traverse Time + Handling Time

Process time is the sum of the following:

- Pocket scribing time: this is the sum of the operation-level scribing times (cycle times) for each scribed GCD (see Operation Cycle Time formula).
- Rapid traverse time (see formula)
- Handling time (see formula)

Operation Cycle Time = Pocket Perimeter / Scribing Rate

This is the scribing time for a single pocket, that is, for a single GCD on which the Scribing operation is performed. Scribing time depends on the following:

- Pocket perimeter: this is the perimeter of the GCD on which the operation is being performed.
- Scribing rate (specified by the machine property **Feed Rate**)

Rapid Traverse Time = Rapid Traverse Distance / Rapid Traverse Rate

Rapid traverse time is estimated based on the following:

- Rapid traverse distance: this is estimated as the fraction of the part's box width specified by the cost model variable **rapidTraverseDistanceFactor** (0.5 in starting point VPEs).
- Rapid traverse rate (specified by the machine property **Rapid Traverse Rate**)

Handling Time = Load Time + Unload Time

Handling time is the sum of the following:

- Load time (see formula)
- Unload time (see formula)

Load Time = Number of Handling Operators * Handling Time per Operator

Load Time is the product of the following:

- Number of handling operators: this is looked up by weight in the lookup table **tblHandlingTimes**. Part weight is material density times part volume (blank area times blank thickness).
- Handling time per operator: this is interpolated from values looked up by part weight in **tblHandlingTimes**. Part weight is material density times part volume (blank area times blank thickness).

Unload Time = Number of Handling Operators * Handling Time per Operator

Unload Time is the product of the following:

- Number of handling operators: this is looked up by weight in the lookup table **tblHandlingTimes**. Part weight is material density times part volume (blank area times blank thickness).
- Handling time per operator: this is interpolated from values looked up by part weight in **tblHandlingTimes**. Part weight is material density times part volume (blank area times blank thickness).

Programming Cost = Programming Rate * Programming Time

By default, this is the product of the machine properties **Programming Rate** and **Programming Time**. Users can override the default on a part-part basis with the setup option **Programming Cost**--see [Scribe Option](#).

Etch Cell Formulas

Note that all of the process time contributes to labor time for the Etch Cell process, since it is the responsibility of the operators to monitor the time spent in the etch tank (which is critical to within seconds) as well as to monitor the tank temperatures and the movement of parts between tanks.

Cycle Time = Process Time * Adjustment Factor

Cycle time is the product of the following:

- Process time (see formula below)
- Adjustment factor (specified by the cost model variable **cycleTimeAdjustmentFactor**). This factor is 1 in aPiori starting point VPEs. VPE

administrators can modify **cycleTimeAdjustmentFactor** in order to adjust cycle times across processes within the current VPE.

Process Time = Total Etch Cycle Time + Handling Time

Process time depends on the following:

- Total etch cycle time: this is the sum of the cycle times for the Etch Cell Cycle child operations (see formula below), together with desmut time (specified by the cost model variable **defaultChemMillDesmutTime**—10 minutes in starting point VPEs) and desmut rinse times (specified by the cost model variable **defaultChemMillDesmutRinseTime**—10 minutes in starting point VPEs).
- Handling time (see formula)

Cycle Time for Etch Cell Cycle = Depth Inspecting Time + Drying Time + Pocket Etching Time + Pocket Peeling Time + Rinsing Time

There is one execution of the Etch Cell Cycle operation for each unique depth of the etched pockets. All pockets that have the same depth are etched in the same Etch Cell Cycle execution. Pockets with the greatest depth are etched first, while the other pockets remain covered with maskant. They are etched to a depth that is the difference between their final depth and the final depth of the next deepest pockets. Then the maskant is peeled from the next deepest pockets, and *they* are etched to the difference between *their* final depth and the final depth of the next, shallower group of pockets, and so on.

Cycle time for each Etch Cell Cycle execution depends on the following:

- Depth inspecting time (see formula)
- Drying time: specified by the cost model variable **defaultChemMillDryingTime** (25 minutes in starting point VPEs)
- Pocket etching time (see formula)
- Pocket peeling time: this is the sum of the cycle times for the Pocket Peeling child operations (see Pocket Peeling Cycle Time formula)
- Rinsing time: this cost model assumes the part is rinsed twice, so this is the time specified by the cost model variable **defaultChemMillRinsingTime** (25 minutes in starting point VPEs) times two.

Depth Inspection Time = Default Depth Inspecting Time * Number of Pockets to Inspect

Depth inspection time is product of the following:

- Default depth inspection time: this is the time to inspect the depth of one pocket, specified by the cost model variable **dimInspectTimePerFeature** (40 seconds in starting point VPEs).
- Number of pockets to inspect: this is the product of the number of pockets etched in the current cycle and the cost model variable **defaultInspectionSampleRatio** (0.25 in starting point VPEs), rounded up to a whole number of pockets.

Pocket Etching Time = Current Etch Step Depth/ Defined Etching Rate

Etching time for all the pockets etched in the current cycle depends only on the following:

- Current etch step depth: this is the difference between the final depth of the pockets currently being etched and the final depth of the pockets to be etched in the next etch cycle (that is, the depth of the next-shallower group of pockets).
- Defined etching rate: by default, this is specified by the cost model variable **defaultChemicalEtchingRate** (0.0381mm/minute in starting point VPEs). Users can override the default on a part-by-part or etch-cycle-by-etch-cycle basis with the setup option **Chemical Etch Rate**—see [Etch Cell Options](#).

Pocket Peeling Cycle Time = Pocket Area / Peeling Rate

This is the per-pocket peeling time. It depends on the following:

- Pocket area (specified by the GCD property **Area**)
- Peeling rate: looked up by the flattened part's projected area in the lookup table **tblChemicalMilling**.

Component Area (mm ²)	Manual Clean Rate (mm ² / s)	Peel Rate (mm ² / s)
1,000,000.00	50,000.00	4,166.00
5,000,000.00	35,000.00	4,166.00
50,000,000.00	20,000.00	4,166.00

Handling Time = Load Time + Unload Time

Handling time is the sum of the following:

- Load time (see formula)
- Unload time (see formula)

Load Time = Number of Handling Operators * Handling Time per Operator

Load Time is the product of the following:

- Number of handling operators: this is looked up by weight in the lookup table **tblHandlingTimes**. Part weight is material density times blank volume.
- Handling time per operator: this is interpolated from values looked up by part weight in **tblHandlingTimes**. Part weight is material density times blank volume.

Unload Time = Number of Handling Operators * Handling Time per Operator

Unload Time is the product of the following:

- Number of handling operators: this is looked up by weight in the lookup table **tblHandlingTimes**. Part weight is material density times part volume, where part volume excludes the total volume removed by etching. The volume removed by etching for a given etched GCD (surface or form) is the GCD's surface area times the etching depth (as defined by the part geometry).
- Handling time per operator: this is interpolated from values looked up by part weight in **tblHandlingTimes**. Part weight is material density times part volume, where part volume excludes the total volume removed by etching. The volume removed by etching for a given etched GCD (surface or form) is the GCD's surface area times the etching depth (as defined by the part geometry).

DeMask Formulas

Cycle Time = Process Time * Adjustment Factor

Cycle time is the product of the following:

- Process time (see formula below)
- Adjustment factor (specified by the cost model variable **cycleTimeAdjustmentFactor**). This factor is 1 in aPiori starting point VPEs. VPE administrators can modify **cycleTimeAdjustmentFactor** in order to adjust cycle times across processes within the current VPE.

Process Time = Operations Time + Handling Time

Process time depends on the following:

- Operations time: this is the sum of the cycle times for each child operation. See the formulas for Peeling Residual Maskant Cycle Time and Dressing Edges Cycle Time, below.
- Handling time (see formula)

Peeling Residual Maskant Cycle Time = Residual Area / Peeling Rate

Cycle time for peeling the residual maskant off the part depends on the following:

- Residual area: this is the portion of the part not subject to any etching in any step of the process. That is, it is the surface area of the blank minus the surface area of the etched portions.
- Peeling rate: looked up by the part's projected area in the lookup table **tblChemicalMilling**.

Component Area (mm ²)	Manual Clean Rate (mm ² / s)	Peel Rate (mm ² / s)
1,000,000.00	50,000.00	4,166.00
5,000,000.00	35,000.00	4,166.00
50,000,000.00	20,000.00	4,166.00

Dressing Edges Cycle Time = Edge Length / Dressing Rate

This is the cycle time for dressing the edges of an etched GCD. It depends on the following:

- Edge length: this is the GCD perimeter, that is, the perimeter of the etched pocket.
- Dressing rate: specified by the cost model variable **defaultEdgeDressingRate** (10 mm/sec in starting point VPEs).

Handling Time = Load Time + Unload Time

Handling time is the sum of the following:

- Load time (see formula)
- Unload time (see formula)

Load Time = Number of Handling Operators * Handling Time per Operator

Load Time is the product of the following:

- Number of handling operators: this is looked up by weight in the lookup table **tblHandlingTimes**. Part weight is material density times part volume, where part volume excludes the total volume removed by etching. The volume removed by etching for a given etched GCD (surface or form) is the GCD's surface area times the etching depth (as defined by the part geometry).
- Handling time per operator: this is interpolated from values looked up by part weight in **tblHandlingTimes**. Part weight is material density times part volume, where part volume excludes the total volume removed by etching. The volume removed by etching for a given etched GCD (surface or form) is the GCD's surface area times the etching depth (as defined by the part geometry).

Unload Time = Number of Handling Operators * Handling Time per Operator

Unload Time is the product of the following:

- Number of handling operators: this is looked up by weight in the lookup table **tblHandlingTimes**. Part weight is material density times part volume, where part volume excludes the total volume removed by etching. The volume removed by etching for a given etched GCD (surface or form) is the GCD's surface area times the etching depth (as defined by the part geometry).
- Handling time per operator: this is interpolated from values looked up by part weight in **tblHandlingTimes**. Part weight is material density times part volume, where part volume excludes the total volume removed by etching. The volume removed by etching for a given etched GCD (surface or form) is the GCD's surface area times the etching depth (as defined by the part geometry).

Batch Setup Time

For machining processes other than milling and turning processes, time to set up a production batch is generally based on the machine property **Setup Time**.

For milling and turning processes, time to set up a production batch is based, by default, on a number of factors, including the following:

- Time to install workholder (0 by default, but see the **PSO Install Workholder** in [Machining Process-level Options](#))
- Cleanup time (0 by default, but see the **PSO Cleanup Time** in [Machining Process-level Options](#))
- Number of tools used by all operations in the current process (see [Tool Selection for Machining](#))
- Number of part setups (see [Working with Part Setups and SetupAxis GCDs](#))
- Cycle time (see [Process Cycle Time](#))

Note Batch setup time is assumed to include time to mill or turn one pallet's worth of parts (there is one part per pallet by default, but see the **PSO Parts in Pallet** in [Machining Process-level Options](#)). This is intended to guard against the risk of scrapping the first pieces production run. It is why cycle time is listed above as a factor affecting batch setup time.

You can override this calculation, and specify batch setup time explicitly with the PSO **Batch Setup Time**—see [Machining Process-level Options](#).

Process Cycle Time

For most machining processes, cycle time is the sum of the cycle times of the process's child operations, together with tool indexing time and tool replacement time. VPE administrators can globally adjust process cycle times by specifying a value for the cost model variable `cycleTimeAdjustmentFactor`.

Cycle Time = Process Time * Cycle Time Adjustment Factor

Cycle time is the product of the following:

- Process time: unadjusted cycle time for the current process. See the formula below.
- Cycle Time Adjustment Factor: value of the cost model variable `cycleTimeAdjustmentFactor`. This is set to 1 in aPriori starting point VPEs. VPE administrators can change the cost model variable to globally adjust cycle times for machining.

Process Time = Child Operation Cycle Times + Tool Indexing Time + Tool Replacement Time

Process time is the sum of the following:

- Child operation cycle times: sum of the cycle times of all child operations (including setup operations) of the process. See [Operation Cycle Time and Cut Time Calculations](#).
- Tool indexing time: total time required for tool indexing for all operations of the process. See the formula below.
- Tool replacement time: total time required for replacing worn out tools for all operations of the process. See the formula below.

Tool Replacement Time = Number of Worn Out Tools * Single Tool Replacement Time

Tool replacement time is the product of the following:

- Number of worn out tools: sum over all operations in the process (that use tools) of the tool life fraction for that operation—see [Expendable Tooling Costs](#). For example, suppose a process has two child operations, and in one operation the tool is used for 10% of its associated tool life, while in the other operation the tool is used for 5% of its associated tool life; in this case the number of worn out tools is considered to be $0.1 + 0.05 = 0.15$.
- Single tool replacement time: time required to replace a single worn out tool. This is the value of the machine property **Time to Replace Dull Tool**.

To remove tool replacement time from the cycle time calculation, set the cost model variable `toolReplacementTimeSwitch` to 0.

Tool Indexing Time = Number of Times a Tool Must Be Indexed * Single Tool Indexing Time / Number of Parts in Pallet

Tool indexing time depends on the following:

- Number of times a tool must be indexed: sum of the tool counts of all the process's setups. A setup's tool count is the number of distinct tools used by the operations that use that setup. Tools are considered distinct if they differ with regard to either tool family or tool diameter. Note that this can sum to more than the process's total number of distinct tools, since more than one setup might use the same tool. Indexing occurs for each use of a distinct tool by a setup.
- Single tool indexing time: time required for the current machine to index a single tool. This is the value of the machine property **Index Time**.
- Number of parts in pallet: see the PSO **Parts in Pallet** in [Machining Process-level Options](#). aPiori assumes that once a tool is loaded into the spindle, the operations involving that tool will be performed on each part in the pallet before switching to the next tool, so the total tool indexing time is amortized across the total number of parts in the pallet.

Expendable Tooling Costs

Machining operations that use tools incur the cost for the tools, amortized over the life of the tool.

Tool Cost = Tool Life Fraction * Tool Life Cost * Tool Cost Adjustment

- Tool life fraction: fraction of the tool's life used up by the current operation. See the formula below.
- Tool life cost: total cost of the tool. Established by tool selection—see [Tool Selection for Machining](#).
- Tool cost adjustment: value of the cost model variable **toolCostAdjustmentFactor**. This defaults to 1. VPE administrators can change the cost model variable to globally adjust tool costs for machining.

Tool Life Fraction = Chipmaking Time / Tool Life

- Chipmaking time: chipmaking time for the current operation—see [Operation Cycle Time and Cut Time Calculations](#).
- Tool life: amount of chipmaking time for which the tool can be used before it is worn out. An initial value for this is established by tool selection (see [Tool Selection for Machining](#)). aPiori uses Taylor's equation for tool life expectancy with the data from **mtblToolLifeCompensation** to adjust the initial value based on the feeds, speeds in use for the current operation. The adjusted value is used in this formula.

Expendable tooling costs for keyway broaching are not based on the above formulas; rather they are based on typical per operation expendable tooling costs as specified by the toolshop variable **expendableToolingCost_PullTypeKeywayBroach** (for Single Pass Keyway Broaching) or **expendableToolingCost_ShimTypeKeywayBroach** (for Multipass Keyway Broaching).

See also [Bench Operation Formulas](#).

User Inputs for Machining

Most of the machining processes and operations have process setup options that allow the user to specify inputs that affect how machining times and costs are calculated.

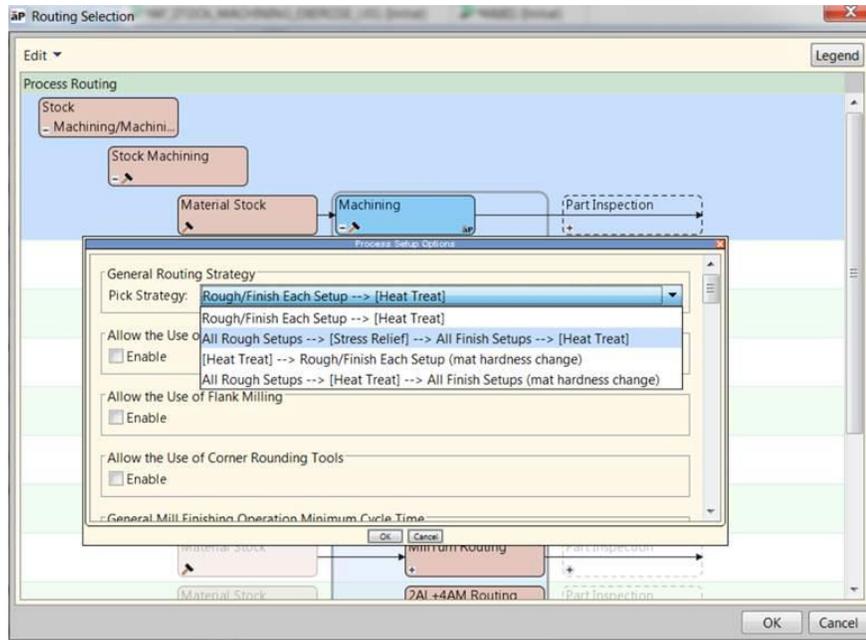
While there are different options available for different processes and operations, many of the options are common across processes and operations. aPriori provides the following sets of options:

- Machining Node Process Setup Options
- Stock Machining Node Process Setup Option
- Machining Process-level Options
- Surface Finishing Milling Options
- Hole Making Options
- Rough Turning Options
- Finish Turning Options
- Edge Finishing Option
- Threading Options
- Pocket Rough Milling Options
- Slot Milling Options
- Groove Milling Options
- Slot Rough Milling Options
- Dovetail Finishing Options
- Surface Rough Milling Options
- Bulk Milling Options
- Keyway Broaching Options
- Material Stock

Machining Node Process Setup Options

Following are the process setup options for the Machining node (right click the Machining node in the Manufacturing Process pane, and select **Process Setup Options...**).

- **Ignore Machine Spindle Limit:** specifies whether to apply an upper bound on tool speed, based on the machine property **Spindle Speed**. See [Adjusted Feed and Speed](#). By default the bound is applied. Check the checkbox to ignore the limit.
- **Ignore Machine Power Limit:** specifies whether to apply a cut time adjustment based on the machine property **Spindle Power**. By default the adjustment is applied. Check the checkbox to eliminate the adjustment.
- **General Routing Strategy:** indicates the part setup and operation sequencing strategy in effect. The strategy can impact the number of times a part is setup and therefore greatly affect the cost of the part.



The default policy is specified by the cost model variable **defaultMachiningStrategyMode**; in starting point cost models, the default strategy is **Rough/Finish Each Setup --> [Heat Treat]**. In this strategy, it is assumed that all possible roughing and finishing operations are performed on each setup, prior to any optional Heat Treatments which may occur post-machining.

To override the default, select one of the following options:

- **All Rough Setups --> [Stress Relief] --> All Finish Setups --> [Heat Treat]**.

In this strategy, all features are roughed from all setups required, and then the part is re-setup for finish machining. When you choose this strategy, the number of setups is increased and each setup contains either only roughing or only finishing operations. Note that choosing this strategy does not automatically include a Stress Relief process in the routing, but represents a common use-case for using such a machining strategy. Automatic inclusion of Stress Relief processes can be configured if desired; please consult aPriori Support or aPriori Professional Services if interested.

- **[Heat Treat] --> Rough/Finish Each Setup (matl hardness change)**

Use this strategy when the material being machined has been heat treated so that its hardness is greater than the hardness specified in the aPriori materials list. For example, if a part is cast, and then heat-treated and subsequently machined, the increased material hardness impacts all machining operations. For this strategy, you also should set the machining process setup option **Material Hardness Achieved Through Heat Treatment** in order to specify the increased material hardness. aPriori then adjusts machining feeds and speeds for all machining operations, so that cycle time computations properly account for the impact of Heat Treatment.

- **All Rough Setups --> [Heat Treat] --> All Finish Setups (matl hardness change)**

In this strategy, all features are roughed from all setups required, and then the part is re-setup for finish machining. Choose this strategy when the part is heat treated subsequent to rough machining but prior to finish machining. In conjunction, also set the machining process setup option **Material Hardness**

Achieved Through Heat Treatment in order to specify the increased material hardness. aPriori then adjusts machining feeds and speeds for the finishing operations, so that finishing cycle time computations properly account for the impact of Heat Treatment.

- **Rough Milling Aggression Adjustment Dial:** specifies the percentage by which to adjust the aggressiveness of rough milling in order to, for example, trade shortened tool life for decreased cutting time. The value is the percentage by which to increase rough milling tool speed (see Adjusted Feed and Speed). Negative values decrease aggressiveness. For example, a value of 25 increases speed by 25% (adjusted speed = 1.25 * initial speed), and a value of -25 decreases speed by 25% (adjusted speed = 0.75 * initial speed). The default value is 0. Enter a value greater than or equal -99.
- **Rough Material Removal Approach:** specifies one of the following approaches:
 - **Roughing - High Feed/High Speed**
 - **Roughing – High Volume Milling**
 - **Roughing – aPriori Traditional (default)**

The approach is used (along with tool diameter, tool series, and material cut code) in order to interpolate feed and speed (and various other tool properties, such as cut depth) from the lookup table tblMilling. See [Interpolated and User-specified Feed and Speed](#).

- **Hole Bottom Geometry Interpretation:** By default in starting point VPEs, the cost model does not interpret CAD-modeled hole bottom geometry literally; it assumes that hole bottoms are conical in shape, regardless of how they are modelled in CAD. That is, by default in starting point VPEs, the cost model assumes that the actual hole bottom is produced by the tip of a standard drilling tool, and that no milling operations are required to achieve the desired shape.

VPE administrators can customize this default with the cost model variable **flatHoleBottoms**. Users can override the default behavior on a part-by-part basis with this setup option. The setup option has two possible settings:

- **Flexible:** This is the default. Hole bottoms are *not* interpreted literally. Milling operations are *not* assigned to the hole-bottom surfaces. The hole is assumed to be made by a drilling sequence alone.
- **Literal:** Hole bottoms are interpreted literally. Milling operations are assigned to the hole-bottom surfaces, if necessary.

See [Hole Bottom Geometry and Hole Bottom Finishing](#) for more information.

- **Material Hardness Achieved Through Heat Treatment.** Specifies the material hardness subsequent to heat treatment. Enter a value using the Brinell scale.
- **Machining Automation Level:** indicates how aggressive aPriori should be in the assignment of machining operations to GCDs, and how much user intervention aPriori should anticipate.

Select one of the following options:

- **Fully Automated:** aPriori anticipates less user intervention in costing. In this mode, aPriori aggressively tries to assign operations to each GCD, even if it means using relatively more setup axes (see [Working with Part Setups and SetupAxis GCDs](#)) and assigning relatively difficult, less efficient operations.

GCDs that cannot be otherwise assigned a finishing operation are assigned General Mill Finishing.

- **Semi-Automated:** aPriori anticipates user intervention after costing in this mode. This is a less aggressive mode in which aPriori assigns only relatively easy-to-perform, efficient operations to each GCD, using only principle and user activated setup axes (see [Working with Part Setups and SetupAxis GCDs](#)). If a GCD cannot be assigned an operation, it is left uncosted and appears as a **Feature to Review** in the Manufacturing Process pane and the Heat Map. See [Semi-automated Costing](#) for more information.
- **Allow the Use of Flat End Mill Contouring Where Possible:** If a Contouring operation is selected for a Planar Face, Curved Wall, or Curved Surface GCD, this option allows for the use of flat bottom, bull nose end mill tools to perform the Contouring operation, rather than a ball mill, typically resulting in an improved chip-making cycle time. You can enable this technique with this setup option. The technique is disabled by default.

If enabled and selected, the technique uses a pass step of 5% of the selected tool diameter. The cost model variable **flatEndMillContouringStepoverPercentage** controls this default.

- **Allow the Use of Flank Milling:** Flank Milling allows for the use of a simultaneous 5-axis side milling technique for CurvedSurface GCDs with a Ruled parameter of true, as well as for partially undercut Planar Faces and Curved Walls. You can enable this technique with this setup option. The technique is disabled by default.
- **Allow the Use of Corner Rounding Tools:** Special corner rounding tools are not used by default. You can enable their use with this setup option.
- **General Mill Finishing Operation Cycle Time:** Set this higher for a larger penalty for problematic surfaces. Set this to 0 to allow aPriori to generate its best estimate of cycle time for all features. The default setting is the value of the cost model variable **minGMFCycleTime** (0 in starting point VPEs).
- **Specify General Milling Speed:** how fast the tool turns in unit distance per unit time; that is, the speed at which a point on the outer edge of the tool moves along the circular path around the center of the tool. This value is used for all turning operations, unless overridden by one of the following setup options:
 - **Specify Cutting Speed for Contouring** (see below)
 - **Specify Cutting Speed for Facing** (see below)
 - **Specify Cutting Speed for Side Milling** (see below)
 - GCD-specific setup option (see [Setup Axes and Operation Feasibility](#))

The value of this option is used (along with feed, tool diameter, and cutting width) to determine area removal rate (see **General Area Removal Rate** in [Working with the Heat Map](#)). See [Operation Cycle Time and Cut Time Calculations](#) for more information on how speed contributes to cutting time.

Note that this value is adjusted to compensate for various factors, including machine spindle speed limitations and stock hardness. The value is also adjusted by multiplying by the cost model variable **millSpeedAdjustment**. The adjusted value is used to help determine area removal rate.

Select one of the following options:

- **Use Default Milling Speed Settings:** aPriori determines the milling speed for each operation and surface by interpolation from data tables based on tool series, tool diameter, and material cut code--see [Tool Selection](#).
- **Override Milling Speed:** enter a speed in meters per minute to be used for all milling operations on all surfaces (unless overridden by a GCD-specific setup option –see [Surface Finishing Milling Options](#)).
- **Contouring Area Ratio Threshold:** specifies the threshold at which 3-Axis Mill contouring is considered difficult, for the purposes of operation assignment in Semi-automated Machining mode (see [Semi-automated Costing](#)). If a GCD's surface area, as a fraction of the total surface area of the current part, is greater than this threshold, contouring is considered difficult. In Semi-automated Machining mode, difficult contouring is considered infeasible for the GCD.

Select one of the following options:

- **Default Value:** 0.001, in aPriori's baseline VPEs. Administrators can override this default value with the cost model variable **contouringAreaRatioThreshold**.
- **User Override:** enter a value between 0 and 1.
- **Specify General Turning Speed:** turning speed in unit distance per unit time. This value is used for all turning operations, unless overridden by the setup option **Specify Rough Turning Speed** (see below) or by a GCD-specific setup option—see [Surface Finishing Milling Options](#). The value is used to help determine cutting time.

Note that this value is adjusted to compensate for various factors, including machine limitations and stock hardness. The value is also adjusted by multiplying by the cost model variable **turningSpeedAdjustment**. The adjusted value is used to help determine cutting time.

Select one of the following options:

- **Use Default Turning Speed Settings:** aPriori determines the turning speed for each operation and surface by lookup in data tables based on tool series, tool diameter, and material cut code.
- **Override Turning Speed:** enter a speed in meters per minute to be used for all turning operations (unless overridden by the setup option **Specify Rough Turning Speed** or a GCD-specific setup option).
- **Easy Side Milling Length to Diameter Ratio:** specifies the threshold at which 3-Axis Mill side milling is considered easy, for the purposes of operation assignment in Semi-automated Machining mode (see [Semi-automated Costing](#)). If side milling a GCD requires a tool whose length-to-diameter ratio (length divided by diameter) exceeds this threshold, side milling is considered difficult. In Semi-automated Machining mode, difficult side milling is considered infeasible (tool selection fails) for the GCD.

Select one of the following options:

- **Default Value:** 3, in aPriori's baseline VPEs. Administrators can override this default value with the cost model variable **easyL2DRatio**.
- **Override Easy Side Milling Length to Diameter Ratio:** enter a value greater than or equal to 0.01.
- **Maximum Side Milling Length to Diameter Ratio:** specifies the threshold at which side milling is considered infeasible. If side milling a GCD requires a tool whose

length-to-diameter ratio (length divided by diameter) exceeds this threshold, tool selection fails, and the GCD may be assigned to a multi-approach sequence or to General Mill Finishing.

Select one of the following options:

- **Default Value:** 8 in aPriori's starting point VPEs. Administrators can override this default value with the cost model variable **difficultL2DRatio**.
- **Override Maximum Side Milling Length to Diameter Ratio:** enter a value greater than or equal to 0.01.
- **Specify Drilling Speed:** how fast the tool turns in unit distance per unit time. This value is used for all drilling operations, unless overridden by a GCD-specific setup option—see [Surface Finishing Milling Options](#). The value is used to help determine area removal rate (see Area Removal Rate in [Working with the Heat Map](#)).

This value is adjusted to compensate for various factors, including machine limitations and stock hardness. The value is also adjusted by multiplying by the cost model variable **drillSpeedAdjustment**. The adjusted value is used to help determine area removal rate.

By default, aPriori determines this value by interpolation from data tables based on tool series, tool diameter, and material cut code.

To override the default, use the following option:

- **Override Drilling Speed:** enter a speed in meters per minute.
- **Specify Cutting Speed for Contouring:** how fast the tool turns in unit distance per unit time; that is, the speed at which a point on the outer edge of the tool moves along the circular path around the center of the tool. This value is used for all contouring operations, unless overridden by a GCD-specific setup option—see [Surface Finishing Milling Options](#). The value is used (along with feed, tool diameter, and cutting width) to determine area removal rate (see Contouring Removal Rate in [Working with the Heat Map](#)). See [Operation Cycle Time and Cut Time Calculations](#) for more information on how speed contributes to cutting time.

Note that the value of this setup option is adjusted to compensate for various factors, including machine spindle speed limitations and stock hardness. The value is also adjusted by multiplying by the cost model variable **millSpeedAdjustment**. The adjusted value is used to help determine area removal rate.

By default, aPriori determines the milling speed for each surface and operation by interpolation from data tables based on tool series, tool diameter, and material cut code (see [Tool Selection](#)).

To override the default, use the following option:

- **Override Cutting Speed for Contouring:** enter a speed in meters per minute to be used for all contouring operations on all surfaces (unless overridden by a GCD-specific setup option).
- **Specify Cutting Speed for Facing:** how fast the tool turns in unit distance per unit time; that is, the speed at which a point on the outer edge of the tool moves along the circular path around the center of the tool. This value is used for all facing operations, unless overridden by a GCD-specific setup option (see

Surface Finishing Milling Options). The value is used (along with feed, tool diameter, and cutting width) to determine area removal rate (see Facing Area Removal Rate in *Working with the Heat Map*). See *Operation Cycle Time and Cut Time Calculations* for more information on how speed contributes to cutting time.

Note that the value of this option is adjusted to compensate for various factors, including machine spindle speed limitations and stock hardness. The value is also adjusted by multiplying by the cost model variable **millSpeedAdjustment**. The adjusted value is used to help determine area removal rate.

By default, aPriori determines the milling speed for each surface and operation by interpolation from data tables based on tool series, tool diameter, and material cut code (see *Tool Selection*).

To override the default, use the following option:

- **Override Cutting Speed for Facing**: enter a speed in meters per minute to be used for all facing operations on all surfaces (unless overridden by a GCD-specific setup option).
- **Specify Cutting Speed for Side Milling**: how fast the tool turns in unit distance per unit time; that is, the speed at which a point on the outer edge of the tool moves along the circular path around the center of the tool. This value is used for all side milling operations, except those overridden by a GCD-specific value—see *Surface Finishing Milling Options*. The value is used (along with feed, tool diameter, and cutting width) to determine area removal rate (see Side Milling Area Removal Rate in *Working with the Heat Map*). See *Operation Cycle Time and Cut Time Calculations* for more information on how speed contributes to cutting time.

Note that the value of this option is adjusted to compensate for various factors, including machine spindle speed limitations and stock hardness. The value is also adjusted by multiplying by the cost model variable **millSpeedAdjustment**. The adjusted value is used to help determine area removal rate.

By default, aPriori determines the milling speed for each surface and operation by interpolation from data tables based on tool series, tool diameter, and material cut code (see *Tool Selection*).

To override the default, use the following option:

- **Override Cutting Speed for Side Milling**: enter a speed in meters per minute to be used for all side milling operations on all surfaces (unless overridden by a GCD-specific setup option).
- **Specify Rough Turning Speed**: turning speed in unit distance per unit time. This value is used for all rough turning operations, except those that override this value with a GCD-specific setup option. The value is used to help determine cutting time.

Note the value of this option is adjusted to compensate for various factors, including machine spindle speed limitations and stock hardness. The value is also adjusted by multiplying by the cost model variable **turningSpeedAdjustment**. The adjusted value is used to help determine area removal rate.

By default, aPriori uses data tables to determine the turning speed for all rough turning operations (except those overridden with a GCD-specific setup option).

The data table lookups are based on tool series, tool diameter, and material cut code.

To override the default, use the following option:

- **Override Rough Turning Speed:** enter a speed in meters per minute to be used for all rough turning operations (except those overridden by a GCD-specific setup option).
- **Maximum Drill Size:** maximum tool diameter for drilling operations. If a GCD requires a tool whose diameter exceeds this value, drilling is considered infeasible. By default, tool diameter for drilling is constrained only by the ranges supported by the available tool families. To specify a maximum, use the following option:
 - **Override Max Drill Size:** enter a value in millimeters (or inches, if you have enabled English units).
- **Maximum Bend Radius for Indirect Filleting:** maximum fillet radius of a GCD for which indirect filleting is feasible. The default setting is the percentage of the part's size specified for indirect filleting in the lookup table **tblOperationSizeRanges** (12% in starting point VPEs), or else the value of the cost model variable **absoluteMaxFilletRadius** (300mm in starting point VPEs), if that's smaller. To override the default, use the following option:
 - **Override Maximum Bend Radius for Indirect Filleting:** enter a value greater than or equal to 0.01 millimeters.
- **Check for Fillet Direction:** By default, for curved surfaces on a 3AL, feasibility for Indirect Filleting does not depend on the existence of an oblique tool approach to the fillet. By setting this option to true, you can override the default and specify that Indirect Filleting is feasible only if there is an Oblique or Oblique Obstructed approach.
- **Maximum Radius for Rounding:** maximum round radius of a GCD for which rounding is feasible. By default, the maximum round radius is the percentage of the part's size specified for rounding in the lookup table **tblOperationSizeRanges**. To override the default, use the following option:
 - **Override Maximum Bend Radius for Indirect Filleting:** enter a non-negative value in millimeters (or inches, if you have enabled English units).
- **Facing Maximum Tool Count:** By default in starting point VPEs, the total number of distinct tool diameters used for face milling the current part's planar faces has an upper limit of between 4 and 6 (depending on part geometry--see [Diameter Selection for Planar Face Facing](#)). VPE administrators can customize the default limit with the cost model variable **maxFacingToolsDefault**. Users can customize or remove the limit with this setup option. Select one of the following options:
 - **Unlimited number of facing tools:** in this case, potentially, each faced surface uses a distinct tool diameter.
 - **Limited number of facing tools:** this is the default mode. Enter a limit greater than or equal to 2.

See [Diameter Selection for Planar Face Facing](#) for more information.

- **Estimated Minimum Facing Diameter:** By default, part-specific preferred diameters are spread out between the minimum and maximum preselected diameters, snapped down to the nearest industry-standard tool size (see [Diameter Selection](#)

- for Planar Face Facing). To override the default minimum part-specific preferred diameter, select the following option:
- **Override estimated minimum:** enter a value greater than or equal to 0.254mm.
See [Diameter Selection for Planar Face Facing](#) for more information.
 - **Estimated Maximum Facing Diameter:** By default, part-specific preferred diameters are spread out between the minimum and maximum preselected diameters, snapped down to the nearest industry-standard tool size (see [Diameter Selection for Planar Face Facing](#)). To override the default minimum part-specific preferred diameter, select the following option:
 - **Override estimated maximum:** enter a value greater than or equal to 0.254mm..
See [Diameter Selection for Planar Face Facing](#) for more information.

Stock Machining Node Process Setup Option

The Stock Machining routing node provides the following setup options:

- **Roughing Technique:** By default in starting point VPEs, roughing is performed with bulk milling. VPE administrators can customize the default with the cost model variable **defaultRoughingTechnique**. You can override the default on a per-part basis with this setup option. Select one of the following:
 - **All Bulk Milling:** all material removed by roughing is converted to chips. If the part uses plate stock, this assumes a single part is machined from a stock piece; if the part uses bar stock, this assumes the part is cut off from the bar. By default in starting point VPEs, stock thickness is set to the next standard stock thickness larger than the finished part thickness (see the process setup option **Snap Up to a Standard Stock Height** in [Material Stock Options](#)), and stock allowances in the length and width dimensions are determined as a percentage of part size (see [Stock Machining Material Stock Allowances](#)).
 - **Perimeter Milling with Dropoff:** enables perimeter cutting as a 3-axis mill, 4-axis mill, or 5-axis mill operation. See [Perimeter Milling Operation](#). This option is available for plate stock only. Assumes a single part is machined from a stock piece. By default in starting point VPEs, stock thickness is set to the next standard stock thickness larger than the finished part thickness (see the process setup option **Snap Up to a Standard Stock Height** in [Material Stock Options](#)), and stock allowances in the length and width dimensions are determined as a percentage of part size (see [Stock Machining Material Stock Allowances](#)).
 - **Plate Cutting with Dropoff:** if the selected stock is plate, this enables waterjet, plasma, oxyfuel, or laser perimeter cutting. See [Stock Machining Routing and Plate Stock](#). This assumes multiple parts are machined from a plate. Material utilization is calculated based on a rectangular nesting pattern. By default in starting point VPEs, stock thickness is set to the next standard stock thickness larger than the finished part thickness (see the process setup option **Snap Up to a Standard Stock Height** in [Material Stock Options](#)). Length and width stock allowances are assumed to be zero. See [Stock Machining Material Stock Allowances](#) and [Material Stock Options](#).

Note that if plate stock is not selected, this setting is ignored, and default roughing is used. Note also that, in starting point VPEs, plate stock is auto-selected by aPriori only if the part width is greater than 142.4mm and the

height-to-width ratio is less than 0.25. VPE administrators can customize these thresholds with the cost model variables **minPlateTriggerWidth** and **maxPlateTriggerHeightOverWidth**.

- **Enable Scrap Material Credit:** By default in starting point VPEs, the cost model assumes that material scrap is *not* sold for credit. Administrators can customize the default with the cost model variable **enableScrapMaterialCredit** (**false** in starting point VPEs). With this setup option, users can override the default on a per-part basis.

Enabling scrap material credit increases material utilization and decreases material cost. The credit rate is specified as a percentage of the material rate by the material property **Scrap Cost Percent**.

- **Enable Scrap Part Credit:** By default in starting point VPEs, the cost model assumes that the material from scrapped parts is *not* sold for credit. Administrators can customize the default with the cost model variable **enableScrapPartCredit** (**false** in starting point VPEs). With this setup option, users can override the default on a per-part basis.

Enabling scrap part credit increases material utilization and decreases material cost. This includes credit for parts scrapped by this process as well as by downstream processes. The credit rate is specified as a percentage of the material rate by the material property **Scrap Cost Percent**.

Machining Process-level Options

Machining processes provide the following options (not all processes provide all options):

- **Workholder Type:** drives **Batch Setup Time**.
 - **Use default value:** turning uses a **3 Jaw Chuck** by default. Milling uses a **Plain Milling Vise** by default, if the part is small enough; otherwise **Non-modular Fixturing** is used by default. A part is small enough if its largest dimension does not exceed the value of the cost model variable **maxViseSize** (406.4mm in starting point VPEs).
 - **User override:** choose a type from the dropdown list. (The items in the list are taken from the lookup table **tblInstallingMillingWorkholders** or **tblInstallingTurningWorkholders**.)

Notes on selected milling workholder types:

- **Adjustable Milling Vise:** the workpiece *angle* is adjustable.
 - **Non-modular Fixturing:** this is a custom fixture dedicated to a specific part or family of parts.
 - **Table Clamping:** the workpiece is clamped so that clamping force is transferred directly to table.
- **Batch Setup Time:** total setup time for a batch. This time is attributed to individual parts by dividing the batch setup time by the batch size specified on the **Production Info** tab of the **Cost Object** window.
 - **Use default value:** calculated setup time, based on a number of considerations, including tool count, setup count. See also **Parts in Pallet**, **Install Workholder**, and **Cleanup Time**, below.
 - **User override:** specify a value in hours.

- **Fixture Cost:** cost of the required fixture. Fixture cost is amortized over the total production volume.
 - **Use default value:** calculated cost to build the fixture. The calculation is based on a number of factors, including the number of different tools required by the operation, as well as the machine labor rate (as specified by the machine property `workcenterLaborRate` and the cost model variable `laborRateAdjustmentFactor`) and overhead rate (as specified by the machine property `workcenterOverheadRate` and the cost model variable `overheadRateAdjustmentFactor`).
 - **User Override:** specify a cost to override the default.
- **Hard Tooling Cost:** cost of additional hard tooling required to machine the part, such as the cost of jigs. Hard tooling cost is amortized over the total production volume. Select one of the following options:
 - **Use default value:** hard tooling cost defaults to 0 in aPriori starting point VPEs.
 - **User override:** specify a cost to override the default
- **NC Programming Cost:** NC programming and debugging cost for the current part. Select one of the following options:
 - **Use default value:** estimate of the programming and debugging cost based on a number of factors, including the number of different tools required by the operation, as well as the machine labor rate (as specified by the machine property `workcenterLaborRate` and the cost model variable `laborRateAdjustmentFactor`).
 - **User Override:** specify a cost to override the default.
- **Parts in Pallet:** number of parts on each pallet. Calculated batch setup time increases as **Parts in Pallet** increases. This defaults to 1 but can be overridden. Select one of the following options:
 - **Use default value:** each pallet is assumed to have a single part.
 - **User override:** specify a whole number greater than 0.
- **Install Workholder:** time to install a workholder. Calculated batch setup time increases as this time increases. This defaults to 0, but can be overridden. Select one of the following options:
 - **Use default value:** the time is assumed to be 0.
 - **User override:** specify a time in seconds.
- **Cleanup Time:** time to clean up after batch is done. Calculated batch setup time increases as this time increases. This defaults to 0, but can be overridden. Select one of the following options:
 - **Use default value:** the time is assumed to be 0.
 - **User override:** specify a time in seconds.
- **Max Facing Tool Diameter:** constrains the tools aPriori selects for facing operations. Select one of the following options:
 - **Use default value:** calculated based on a number of factors, including part dimensions and data in `tblOperationSizeRanges`.
 - **User override:** specify a diameter in millimeters.
- **Max Side Milling Tool Diameter:** constrains the tools aPriori selects for side milling operations. Select one of the following options:

- **Use default value:** calculated based on a number of factors, including part dimensions and data in **tblOperationSizeRanges**.
- **User override:** specify a diameter in millimeters.
- **Max Roughing Tool Diameter:** constrains the tools aPriori selects for roughing operations. Select one of the following options:
 - **Use default value:** calculated based on a number of factors, including part dimensions and data in **tblOperationSizeRanges**.
 - **User override:** specify a diameter in millimeters.
- **Max Contouring Tool Diameter:** constrains the tools aPriori selects for contouring operations. Select one of the following options:
 - **Use default value:** calculated based on a number of factors, including part dimensions and data in **tblOperationSizeRanges**.
 - **User override:** specify a diameter in millimeters.

Surface Finishing Milling Options

aPriori supports a variety of surface finishing operations that can be applied to the different types of surface GCDs, depending on the capabilities of the machining process used. For example, Facing may be applied to PlanarFace GCDs; Side Milling may be applied to PlanarFace and CurvedWall GCDs; Contouring may be applied to PlanarFace, CurvedWall, and CurvedSurface GCDs.

You can specify options for how surface finishing operations are performed on specific GCDs by locating the specific surface finishing operation node of interest in the Manufacturing Process Pane, then locating the relevant surface GCD under it. Right click the GCD to invoke the Process Options editor.

See [Working with Features to Review](#) and [Working with the Heat Map](#) for more information on the use of the options listed in this section.

The following options are available (not all operations support all these options):

- **Number of Finishing Passes:** number of times the tool passes over the entire surface. Chipmaking time increases as the number of passes goes up--see [Chipmaking Time for Surface Finishing Milling Operations](#).
Select one of the following options:
 - **Computed Number of Finishing Passes:** aPriori determines this based on the required tolerance and the lookup table **tblGtolProcessCapabilities**. This typically defaults to 1 in aPriori starting point VPEs.
 - **Override Number of Finishing Passes:** enter a value greater than or equal to 1.
- **Requested Tool Diameter:** diameter of the selected tool. Larger diameters can decrease engagement time (assuming sufficient spindle power)—see [Operation Cycle Time and Cut Time Calculations](#)--and have a more favorable length-to-diameter ratio. Smaller diameters have better corner accessibility.
Select one of the following options:
 - **Use Computed Tool Diameter:** aPriori chooses a tool diameter based on a number of factors, including overall part size, accessibility of the GCD's corners (if any), and the values of setup options that constrain tool size. See [Tool Selection](#) for more information.

- **Override Tool Diameter:** enter the tool diameter in millimeters.
- **Requested Tool Cutting Speed:** how fast the tool turns in unit distance per unit time; that is, the speed at which a point on the outer edge of the tool moves along the circular path around the center of the tool. This value is used (along with feed, tool diameter, and cutting width) to determine area removal rate. See [Operation Cycle Time and Cut Time Calculations](#) for more information on how speed contributes to cutting time.

Select one of the following options:

- **Use Recommended Tool Cutting Speed:** aPiori determines this value by interpolation from data tables based on tool series, tool diameter, and material cut code—see [Tool Selection](#). This value is adjusted to compensate for various factors, including machine spindle speed limitations and stock hardness. The value is also adjusted by multiplying by the cost model variable **millSpeedAdjustment**. The adjusted value is used to help determine area removal rate.
- **Override Tool Cutting Speed:** enter a speed in meters per minute. This value is adjusted to compensate for various factors, including machine spindle speed limitations and stock hardness. The value is also adjusted by multiplying by the cost model variable **millSpeedAdjustment**. The adjusted value is used to help determine area removal rate.
- **Requested Feed per Tooth:** distance the tool travels along the surface of the part per tooth of the tool during one rotation. The number of tool teeth times this value is the distance the tool travels along the surface of the part per rotation of the tool. This value is used (along with speed, tool diameter and cutting width) to determine area removal rate. See [Operation Cycle Time and Cut Time Calculations](#) for more information on how feed contributes to cutting time.

Select one of the following options:

- **Use Computed Feed per Tooth:** aPiori determines this value by interpolation from data tables based on tool series, tool diameter, and material cut code—see [Tool Selection](#). aPiori multiplies this value by the number of teeth to derive tool feed. This value is adjusted to compensate for various factors, including tool reach and required tolerance. Tool feed is also adjusted by multiplying by the cost model variable **millFeedAdjustment**. The adjusted value is used to help determine area removal rate.
- **User Override:** enter a value in millimeters. aPiori multiplies this value by the number of teeth to derive tool feed. This value is adjusted to compensate for various factors, including tool reach and required tolerance. Tool feed is also adjusted by multiplying by the cost model variable **millFeedAdjustment**. The adjusted value is used to help determine area removal rate.
- **Number of Teeth:** number of tool teeth. This value together with feed per tooth determines feed (which affects area removal rate)—see [Operation Cycle Time and Cut Time Calculations](#).

Select one of the following options:

- **Number of teeth:** aPiori determines this value by interpolation from data tables based on tool series, tool diameter, and material cut code—see [Tool Selection](#). aPiori multiplies this value by the feed per tooth to derive tool feed. This value is adjusted to compensate for various factors, including tool reach and required tolerance. Tool feed is also adjusted by multiplying by the

cost model variable **millFeedAdjustment**. The adjusted value is used to help determine area removal rate.

- **User Override:** enter a value greater than or equal to 2.

If you supply a user override for both **Number of Teeth** and **Requested Feed per Tooth**, aPiori multiplies the two values together to derive tool feed.

If you supply a user override for **Number of Teeth**, and you do *not* specify a user override for **Requested Feed per Tooth**, aPiori sets the unadjusted value for feed as follows:

Feed = Interpolated Feed * (Specified Number of Teeth / Interpolated Number of Teeth)

(Interpolated feed and interpolated number of teeth are derived from data tables during tool selection—see [Tool Selection](#).)

In either case, the value is adjusted to compensate for various factors, including tool reach and required tolerance. Tool feed is also adjusted by multiplying by the cost model variable **millFeedAdjustment**. The adjusted value is used to help determine area removal rate.

- **Contouring Tool Stepper:** separation between ball-end mill pass steps, that is, the distance between the tool centerline during successive finishing passes.

Select one of the following options:

- **Use Computed Stepper:** value computed by aPiori based on tool diameter and GCD roughness, as well on the cost model variable **passStepSafetyFactor** (which defaults to 1--the stepper decreases as **passStepSafetyFactor** increases).
- **Override Stepper :** enter a value that does not exceed the tool diameter

Hole Making Options

The options listed below are available for all drilling operations, *except* center drilling and Deep Bore Machine operations:

- **Requested Tool Diameter:** diameter of the selected tool. This value is used (along with speed, feed, hole length, and other factors) to determine cut time.

Select one of the following options:

- **Use Computed Tool Diameter:** aPiori typically chooses a tool diameter based on GCD diameter. See [Tool Selection](#) for more information.
- **Override Tool Diameter:** enter the tool diameter in millimeters.

- **Requested Feed Per Rev:** distance the tool travels through the part per revolution of the tool. This value is used (along with speed, tool diameter, hole length, and other factors) to determine tool axis speed and cut time. See [Operation Cycle Time and Cut Time Calculations](#) for more information on how feed contributes to cutting time.

Select one of the following options:

- **Use Computed Feed Per Rev:** aPiori determines this value by interpolation from data tables based on tool series, tool diameter, and material cut code—see [Tool Selection](#). This value is adjusted to compensate for various factors, including required tolerance. Tool feed is also adjusted by multiplying by the

cost model variable **drillFeedAdjustment**. The adjusted value is used to help determine tool axis speed and cut time.

- **Override Feed Per Rev:** enter a value in millimeters. This value is adjusted to compensate for various factors, including required tolerance. Tool feed is also adjusted by multiplying by the cost model variable **drillFeedAdjustment**. The adjusted value is used to help determine tool axis speed and cut time.
- **Requested Tool Cutting Speed:** how fast the tool turns in unit distance per unit time; that is, the speed at which a point on the outer edge of the tool moves along the circular path around the center of the tool. This value is used to help determine tool axis speed and cut time. See [Operation Cycle Time and Cut Time Calculations](#) for more information on how speed contributes to cutting time.

Select one of the following options:

- **Use Computed Tool Cutting Speed:** aPiori determines this value by interpolation from data tables based on tool series, tool diameter, and material cut code--see [Tool Selection](#). This value is adjusted to compensate for various factors, including machine speed and power limitations. The value is also adjusted by multiplying by the cost model variable **drillSpeedAdjustment**. The adjusted value is used to help determine tool axis speed and cut time.
- **Override Tool Cutting Speed:** enter a speed in meters per minute. This value is adjusted to compensate for various factors, including machine speed and power limitations. The value is also adjusted by multiplying by the cost model variable **drillSpeedAdjustment**. The adjusted value is used to help determine tool axis speed and cut time.

Pecking supports the following additional options:

- **Peck Depth:** depth of a single peck. **Amount of Hole to be Pecked** (see below) divided by **Peck Depth** is the number of pecks to be performed. Select one of the following options:
 - **Use Default:** this is the value of the cost model variable **lengthOfPeck**.
 - **Override:** specify a value in millimeters.
- **Amount of Hole to be Pecked:** depth achieved by all the pecks to be performed. This value divided by **Peck Depth** (see above) is the number of pecks to be performed. Select one of the following options:
 - **Use Computed Value:** length of the GCD (or, if the GCD is part of a multistep hole, length of the multistep hole). (Note that, for holes that are part of a multistep hole, Pecking is always preceded by Center Drilling, which requires that that the GCD is the *smallest* hole of the multistep hole.)
 - **Override:** specify a value in millimeters.

The Boring Enlargement operation sequence (Rough Boring followed by Semi-Finish Boring) supports the following additional options:

- **Number of Rough Boring Passes:** By default, aPiori determines the number of rough boring passes based on the following factors:
 - **Hole radius:** This is the depth of material (measured from the center outwards) that must be removed in order to create the hole.
 - **Depth of the initial drilling pass:** this is the depth of material removed by the Drilling operation, that is, half the diameter of the Drilling tool. In starting point VPEs, the drill diameter for this initial operation of the sequence is 70% of the

hole diameter (or the maximum available drill size, whichever is smaller). VPE administrators can customize this percentage with the cost model variable **enlargementDrillAsFractOfHole**.

- Number of semi-finishing passes (see above)
- Depth of a single semi-finishing pass: This is either 7.2mm or half the depth not removed by initial drilling and finishing, whichever is less.
- Whether a finishing pass is required and, if so, its depth (that is, the depth of material removed by the hole finishing operation). If a finishing pass is required, this is assumed to be 0.3% of the hole radius, provided this value falls between 0.0508mm (0.002 inches) and 0.127 (0.005 inches).
- Depth of a single, typical rough boring pass. This is assumed to be 7.5mm.

aPriori uses this information to determine the depth of material that must be removed by rough boring in order that the total depth of material removed by all operations adds up to the hole radius. The required number of passes is the depth that must be removed by rough boring divided by the depth of a single typical rough boring pass, rounded up to the nearest whole number of passes.

You can override the default on a GCD-by-GCD basis with this setup option; specify a value greater than or equal to 1.

- **Num Semi Finish Boring Passes:** In starting point VPEs, the default, the number of semi-finishing passes is 2. You can customize the default with the cost model variable **defaultNumSemiFinishBoringPasses**. You can override the default on a GCD-by-GCD basis with this setup option; specify a value greater than or equal to 1.

Rough Turning Options

Rough turning operations support the following options:

- **Casting Depth: casting material allowance. This defaults to the value of the cost model variable **finishAllowance**. To override the default, use the following option:**
 - **Casting Depth: enter a value in millimeters greater than or equal to 0.1.**
- **Requested Feed Per Rev:** distance the tool travels along the part per revolution of the workpiece. This value is used to help determine volume removal rate—see [Chipmaking Time for Rough Turning Operations](#).

Select one of the following options:

- **Use Computed Feed Per Rev:** aPriori determines this value by interpolation from data tables—see [Tool Selection](#). This value is adjusted to compensate for various factors, including required tolerance. Tool feed is also adjusted by multiplying by the cost model variable **turningFeedAdjustment**. The adjusted value is used to help determine volume removal rate.
- **Override Feed Per Rev:** enter a value in millimeters. This value is adjusted to compensate for various factors, including required tolerance. Tool feed is also adjusted by multiplying by the cost model variable **turningFeedAdjustment**. The adjusted value is used to help determine volume removal rate.
- **Requested Tool Cutting Speed:** how fast the workpiece turns in unit distance per unit time; that is, the speed at which a point on the outer edge of the workpiece moves along the circular path around the turning axis. This value is used to help

determine volume removal rate. See [Chipmaking Time for Rough Turning Operations](#).

Select one of the following options:

- **Use Recommended Tool Cutting Speed:** aPiori determines this value by interpolation from data tables—see [Tool Selection](#). This value is adjusted to compensate for various factors, including machine spindle speed limitations and stock hardness. The value is also adjusted by multiplying by the cost model variable **turningSpeedAdjustment**. The adjusted value is used to help determine volume removal rate.
- **Override Tool Cutting Speed:** enter a speed in meters per minute. This value is adjusted to compensate for various factors, including machine spindle speed limitations and stock hardness. The value is also adjusted by multiplying by the cost model variable **turningSpeedAdjustment**. The adjusted value is used to help determine volume removal rate.
- **Requested cut depth:** depth of the cut. Use one of the following options:
 - **Use Computed Cut Depth:** determined by tool selection (see [Tool Selection](#)). The value is adjusted based on machine power and limited by material allowance (as specified by the option **Casting Depth**—see above). The adjusted value is used to help determine volume removal rate—see [Chipmaking Time for Rough Turning Operations](#).
 - **Override Cut Depth:** specify a value in millimeters. This value is adjusted based on machine power and GCD size or limited by material allowance (as specified by the option **Casting Depth**—see above). The adjusted value is used to help determine volume removal rate—see [Chipmaking Time for Rough Turning Operations](#).

Finish Turning Options

Finish Turning and Back Finish Turning provide the following options:

- **Number of Finishing Passes:** number of times the tool passes over the GCD surface. Chipmaking time increases as the number of passes goes up—see [Chipmaking Time for Finish Turning Operations](#).

Select one of the following options:

- **Computed Number of Finishing Passes:** aPiori determines this based on the required tolerance and the lookup table **tblGtolProcessCapabilities**. This typically defaults to 1 in aPiori starting point VPEs.
- **Override Number of Finishing Passes:** enter a value greater than or equal to 1.
- **Requested Feed Per Rev:** distance the tool travels along the part per revolution of the workpiece. This value is used to help determine area removal rate—see [Chipmaking Time for Finish Turning Operations](#).

Select one of the following options:

- **Use Computed Feed Per Rev:** aPiori determines this value by interpolation from data tables—see [Tool Selection](#). This value is adjusted to compensate for various factors, including required tolerance. Tool feed is also adjusted by multiplying by the cost model variable **turningFeedAdjustment**. The adjusted value is used to help determine area removal rate.

- **Override Feed Per Rev:** enter a value in millimeters. This value is adjusted to compensate for various factors, including required tolerance. Tool feed is also adjusted by multiplying by the cost model variable **turningFeedAdjustment**. The adjusted value is used to help determine area removal rate.
- **Requested Tool Cutting Speed:** how fast the workpiece turns in unit distance per unit time; that is, the speed at which a point on the outer edge of the workpiece moves along the circular path around the turning axis. This value is used to help determine area removal rate. See [Chipmaking Time for Finish Turning Operations](#).

Select one of the following options:

- **Use Recommended Tool Cutting Speed:** aPiori determines this value by interpolation from data tables—see [Tool Selection](#). This value is adjusted to compensate for various factors, including machine spindle speed limitations and stock hardness. The value is also adjusted by multiplying by the cost model variable **turningSpeedAdjustment**. The adjusted value is used to help determine area removal rate.
- **Override Tool Cutting Speed:** enter a speed in meters per minute. This value is adjusted to compensate for various factors, including machine spindle speed limitations and stock hardness. The value is also adjusted by multiplying by the cost model variable **turningSpeedAdjustment**. The adjusted value is used to help determine area removal rate.

Edge Finishing Option

Chamfering and Rounding provide the following option:

- **Tool Linear Speed Tool:** speed at which the tool moves along the edge, which helps determine cut time. See the formula for Edge Treatment Engagement Time in [Cut Time for Machining Operations](#). Select one of the following options:
 - **Use Computed Tool Linear Speed:** established by tool selection—see [Tool Selection for Machining](#).
 - **User Override:** enter a value in millimeters per second.

Deburring Options

The deburring cost model provides process-level and operation-level setup options. The following process-level options are provided by the Deburr processes (Automated Deburr and Manual Deburr):

- Setup Time per Part
- Number of Deburring Setups per Part
- Default Edge Deburr Tool Type
- Default Surface Deburr Tool Type
- Process Material Feed Rate
- Include Automated Surface Deburr
- Include Manual Surface Deburr

The following operation-level options are provided by the Deburring operations (Automated Edge Deburring, Automated Surface Deburring, Manual Edge Deburring, Manual Surface Deburring, Virtual Automated Edge Deburring Op, and Virtual Manual Edge Deburring Op):

- Number of Edges
- Deburr Tool Type
- Material Feed Rate
- Length of Edge Being Deburred
- Travel Path Length Being Deburred
- Number of Deburr Passes
- Number of Operations

Setup Time per Part

By default, the setup time per part is the product of the following, amortized over the number of parts in a batch:

- Number of part setups required for deburring (see [Number of Deburring Setups per Part](#))
- Default time to perform a single setup of a batch of parts

For Manual Deburring operations, the default time to perform a single setup of a batch of parts is weight based: it is the product of labor handling time and the number of handling operators, which are interpolated from values looked up by part weigh in the lookup table **tblHandlingTimes**.

Equipment	Handling Time (s)	Max Weight (kg)	Num Operators
crane	1,800.00	2,000.00	2.00
crane	2,700.00	9,999,999.00	2.00
forklift	540.00	300.00	1.00
forklift	900.00	500.00	1.00
none	1.00	0.00	1.00
none	2.00	1.00	1.00
none	10.00	5.00	1.00
none	30.00	15.00	1.00
none	45.00	20.00	1.00

For Automated Deburring operations, the default time to perform a single setup of a batch of parts is machine based: it is specified by the machine property **Setup Time**.

Users can override the default on a per-part basis with this setup option. Select one of the following:

- **Weight-Based Time:** determine the setup time based on the weight of the part, and values looked up by part weigh in the lookup table **tblHandlingTimes**.
- **Machine-Based Time:** determine setup itme based on the machine property **Setup Time**.

Number of Deburring Setups per Part

By default in starting point VPEs, the cost model assumes that parts can be deburred using a single setup. If not all GCDs to be deburred are accessible from a single setup, the default can be customized or overridden. Administrators can customize the default with the cost model variable **defaultNumberDeburrSetups** (1 in starting point VPEs). Users can override the default with this setup option.

Number of deburring setups affects [Setup Time per Part](#).

Default Edge Deburr Tool Type

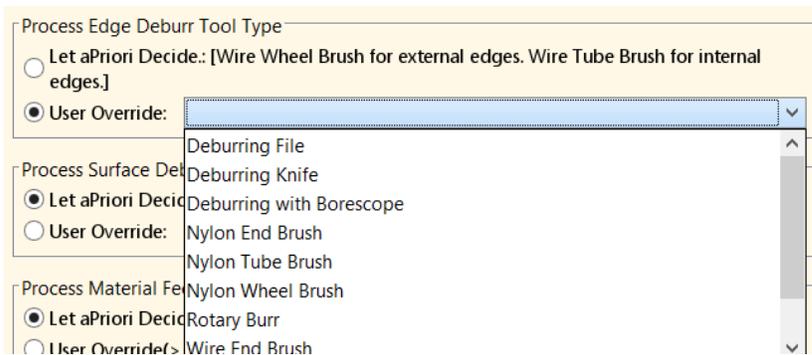
By default in starting point VPEs, edge deburring uses the following tools:

- Internal edge deburring: **Wire Tube Brush**
- External edge deburring: **Wire Wheel Brush**

Administrators can customize the defaults with the following cost model variables:

- **defaultInternalEdgeDeburrToolType**
- **defaultExternalEdgeDeburrToolType**

Users can override the default on a per-part basis with this setup option.

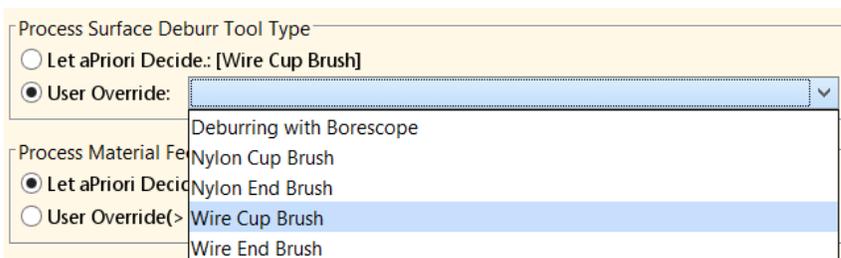


Note that users can also override the tool type on a per-GCD basis with the setup option [Deburr Tool Type](#).

Tool type and material cut code determine the default [Process Material Feed Rate](#), which drives cycle time.

Default Surface Deburr Tool Type

By default in starting point VPEs, surface deburring uses the **Wire Cup Brush** tool type. Administrators can customize the default with the cost model variable **defaultSurfaceDeburrToolType**. Users can override the default on a per-part basis with this setup option.



Note that users can also override the tool type on a per-GCD basis with the setup option **Deburr Tool Type**.

Tool type and material cut code determine the default **Process Material Feed Rate**, which drives cycle time.

Process Material Feed Rate

This is the distance in the feed direction per unit time covered by the deburring machine. By default, this is looked up by tool type and material cut code in the lookup table **tblDeburring**.

Tool Type	Tool Series	Material Cut Code Name	Hardness	Hardness System	Linear Speed (mm / s)
Deburring Brush	Virtual Deburring Brush	9.0	200	Brinell	16.11
Deburring Brush	Virtual Deburring Brush	9.1	200	Brinell	4.62
Deburring Brush	Virtual Deburring Brush	9.2	200	Brinell	1.78
Deburring Brush	Virtual Deburring Brush	9.3	200	Brinell	5.85
Deburring File	Virtual Deburring File	1	200	Brinell	5.85
Deburring File	Virtual Deburring File	1.1	200	Brinell	4.67
Deburring File	Virtual Deburring File	1.2	200	Brinell	4.67
Deburring File	Virtual Deburring File	1.3	200	Brinell	3.38
Deburring File	Virtual Deburring File	1.4	200	Brinell	1.99
Deburring File	Virtual Deburring File	1.5	200	Brinell	

With this setup option, users can override the default on a per-part basis.

Note that users can also override the material feed rate on a per-GCD basis with the setup option **Material Feed Rate**.

Material feed rate drives cycle time. Operation cycle time for a given GCD is given by the following:

$$\text{Deburr Time} = (\text{Deburr Length} * \text{Number of Passes}) / \text{Material Feed Rate}$$

See **Length of Edge Being Deburred**, **Travel Path Length Being Deburred**, and **Number of Deburr Passes**.

Include Automated Surface Deburr

(Automated Deburr process only)

If you include Automated Deburr in your routing, the cost model assumes that only edges are deburred, by default. With this setup option, you can override the default, and specify that all surfaces are deburred as well.

Include Manual Surface Deburr

(Manual Deburr process only)

If you include Manual Deburr in your routing, the cost model assumes that only edges are deburred, by default. With this setup option, you can override the default, and specify that all surfaces are deburred as well.

Number of Edges

(Individual occurrence of virtual edge deburring only)

By default, for virtual edge deburring, the cost model assumes that a single edge is deburred. With this setup option, you can explicitly specify the number of virtual edges to be deburred.

Deburr Tool Type

By default, tool type is chosen as described in [Tool Type Selection for Deburring Operations](#). Users can override the default on per-part basis with the setup options [Default Edge Deburr Tool Type](#) or [Default Surface Deburr Tool Type](#). With this setup option, users can specify the tool type on a per-GCD basis.

Material Feed Rate

This is the distance in the feed direction per unit time covered by the deburring machine. By default, this is looked up by tool type and material cut code in the lookup table `tblDeburring`. With the setup option [Process Material Feed Rate](#), users can override the default on a per-part basis. With this setup option, users can specify the feed rate on a per-GCD basis.

Material feed rate drives cycle time. Operation cycle time for a given GCD is given by the following:

$$\text{Deburr Time} = (\text{Deburr Length} * \text{Number of Passes}) / \text{Material Feed Rate}$$

See [Length of Edge Being Deburred](#), [Travel Path Length Being Deburred](#), and [Number of Deburr Passes](#).

Length of Edge Being Deburred

(Edge Deburring only)

For edges, deburr length is the distance along the entire edge, by default. For virtual deburring, the default edge length is 25.4mm (1 inch). With this setup option, users can override the default on per-GCD basis.

Travel Path Length Being Deburred

(Surface Deburring only)

By default, this is assumed to be one of the following:

- SER length of a PlanarFace
- ¼ the perimeter of a CurvedSurface
- Height of a CurvedWall

With this setup option, users can override the default.

Travel path length, along with feed rate and number of deburr passes, drives cycle time. See [Process Material Feed Rate](#) for more information.

Number of Deburr Passes

By default in starting point VPEs, the number of deburr passes is assumed to be 1. In some cases, it might be desirable to increase the number of passes (for example, when a surface is too wide for the tool to cover in one pass). Administrators can customize the default with the cost model variables `defaultNumDeburrPassesEdge` and `defaultNumDeburrPassesSurface`. With this setup option, users can override the default on a per-GCD basis.

Number of deburr passes, along with feed rate and travel length, drives cycle time. See [Process Material Feed Rate](#) for more information.

Number of Operations

(Virtual Automated Edge Deburring Op and Virtual Manual Edge Deburring Op only)

Specifies the number of occurrences of edge deburring. Each occurrence performs deburring on the number of edges specified by the setup option **Number of Edges** for that occurrence, and uses the tool type, feed rate, edge or travel length, and number of passes specified by the other setup options for that occurrence.

Threading Options

aPriori supports the following thread-making operations:

- Tapping
- Thread Turning
- Thread Milling

Users can indicate that a hole is threaded by either applying a cosmetic thread feature in the CAD system or by manually setting the **Threaded** property of the GCD to **true**. For more information on editing GCD properties, see the "Editing values in the GCD properties table" section of the aPriori *User Guide*.

The following options are available by locating the thread-making operation of interest in the Manufacturing Process pane, then right-clicking the specific hole GCD of interest under the thread-making node:

- **Thread Pitch:** distance between adjacent threads. Select one of the following options:
 - **Default Value:** a value of 1 millimeter is used.
 - **User-specified:** enter a value that uses the units specified by the option **Thread Units**—see below. The default units are millimeters.
- **Thread Units:** units used by the option **Thread Pitch**—see above. The default is millimeters. Select one of the following options:
 - **TPI:** thread per inch.
 - **mm:** millimeters (default).
- **Requested Tool Cutting Speed:** how fast the tool turns in unit distance per unit time; that is, the speed at which a point on the outer edge of the tool moves along the circular path around the center of the tool. This value is used to help determine tool axis speed and cut time. See [Operation Cycle Time and Cut Time Calculations](#) for more information on how speed contributes to cutting time.

Select one of the following options:

- **Use Computed Tool Cutting Speed:** aPriori determines this value by interpolation from data tables based on tool series, tool diameter, and material cut code—see [Tool Selection](#). This value is adjusted to compensate for various factors, including stock hardness and machine limitations. The value is also adjusted by multiplying by the cost model variable **drillSpeedAdjustment**. The adjusted value is used to help determine tool axis speed and cut time.
- **Override Tool Cutting Speed:** enter a speed in meters per minute. This value is adjusted to compensate for various factors, including stock hardness and machine limitations. The value is also adjusted by multiplying by the cost

model variable **drillSpeedAdjustment**. The adjusted value is used to help determine tool axis speed and cut time.

Thread milling provides the following additional options:

- **Thread Length:** length of the threaded portion of the hole. Select one of the following options:
 - **Default Value:** thread length defaults to 10 millimeters.
 - **User-Specified:** enter a value in millimeters.
- **Thread Form:** defaults to metric 60 degrees. Select one of the following options:
 - **Metric 60 deg** (default)
 - **NPT (NT)**
 - **UN 60 deg**

Surface Rough Milling Options

Rough milling provides the following options:

- **Roughing Depth:** casting material allowance. This defaults to the value of the cost model variable **finishAllowance**. To override the default, use the following option:
 - **Casting Depth:** enter a value in millimeters greater than or equal to 0.1.
- **Material Removal Rate:** rate at which material is removed during chipmaking. By default this is based on feed, speed, engagement width, and cut depth (see [Chipmaking Time for Surface Rough Milling](#)). Use the following option to override the default:
 - **Override:** enter a value in cubic millimeters.
- **Requested Tool Diameter:** diameter of the selected tool. Larger diameters can decrease engagement time—see [Operation Cycle Time and Cut Time Calculations](#)--and have a more favorable length-to-diameter ratio. Smaller diameters have better corner accessibility.

Select one of the following options:

- **Use Computed Tool Diameter:** aPiori chooses a tool diameter based on a number of factors, including overall part size, accessibility of the GCD's corners (if any), and the values of setup options that constrain tool size. See [Tool Selection](#) for more information.
- **Override Tool Diameter:** enter the tool diameter in millimeters.
- **Requested Tool Cutting Speed:** how fast the tool turns in unit distance per unit time; that is, the speed at which a point on the outer edge of the tool moves along the circular path around the center of the tool. This value is used (along with feed, tool diameter, and cutting width) to determine area removal rate. See [Operation Cycle Time and Cut Time Calculations](#) for more information on how speed contributes to cutting time.

Select one of the following options:

- **Use Recommended Tool Cutting Speed:** aPiori determines this value by interpolation from data tables based on tool series, tool diameter, and material cut code--see [Tool Selection](#). This value is adjusted to compensate for various factors, including machine spindle speed limitations and stock hardness. The value is also adjusted by multiplying by the cost model

variable **millSpeedAdjustment**. The adjusted value is used to help determine area removal rate.

- **Override Tool Cutting Speed:** enter a speed in meters per minute. This value is adjusted to compensate for various factors, including machine spindle speed limitations and stock hardness. The value is also adjusted by multiplying by the cost model variable **millSpeedAdjustment**. The adjusted value is used to help determine area removal rate.
- **Requested Feed per Tooth:** distance the tool travels along the surface of the part per tooth of the tool during one rotation. The number of tool teeth times this value is the distance the tool travels along the surface of the part per rotation of the tool. This value is used (along with speed, tool diameter and cutting width) to determine area removal rate. See [Operation Cycle Time and Cut Time Calculations](#) for more information on how feed contributes to cutting time.

Select one of the following options:

- **Use Computed Feed per Tooth:** aPiori determines this value by interpolation from data tables based on tool series, tool diameter, and material cut code—see [Tool Selection](#). aPiori multiplies this value by the number of teeth to derive tool feed. This value is adjusted to compensate for various factors, including tool reach and required tolerance. Tool feed is also adjusted by multiplying by the cost model variable **millFeedAdjustment**. The adjusted value is used to help determine area removal rate.
- **User Override:** enter a value in millimeters. aPiori multiplies this value by the number of teeth to derive tool feed. This value is adjusted to compensate for various factors, including tool reach and required tolerance. Tool feed is also adjusted by multiplying by the cost model variable **millFeedAdjustment**. The adjusted value is used to help determine area removal rate.
- **Number of Teeth:** number of tool teeth. This value together with feed per tooth determines feed (which affects area removal rate)—see [Operation Cycle Time and Cut Time Calculations](#).

Select one of the following options:

- **Number of teeth:** aPiori determines this value by interpolation from data tables based on tool series, tool diameter, and material cut code—see [Tool Selection](#). aPiori multiplies this value by the feed per tooth to derive tool feed. This value is adjusted to compensate for various factors, including tool reach and required tolerance. Tool feed is also adjusted by multiplying by the cost model variable **millFeedAdjustment**. The adjusted value is used to help determine area removal rate.
- **User Override:** enter a value greater than or equal to 2.

If you supply a user override for both **Number of Teeth** and **Requested Feed per Tooth**, aPiori multiplies the two values together to derive tool feed.

If you supply a user override for **Number of Teeth**, and you do *not* specify a user override for **Requested Feed per Tooth**, aPiori sets the unadjusted value for feed as follows:

$$\text{Feed} = \text{Interpolated Feed} * (\text{Specified Number of Teeth} / \text{Interpolated Number of Teeth})$$

(Interpolated feed and interpolated number of teeth are derived from data tables during tool selection—see [Tool Selection](#).)

In either case, the value is adjusted to compensate for various factors, including tool reach and required tolerance. Tool feed is also adjusted by multiplying by the cost model variable **millFeedAdjustment**. The adjusted value is used to help determine area removal rate.

- **Radial Cut Depth:** engagement length as a percentage of the tool diameter. Radial cut depth helps determine contact area and cut time. See [Chipmaking Time for Surface Rough Milling](#). The default is 50% in aPriori starting point VPEs. Use the following option to override the default:
 - **User Override:** enter a whole number between 0 and 100, inclusive.
- **Axial Cut Depth:** cut depth as a percentage of the tool diameter. Axial cut depth helps determine contact area and cut time. See [Chipmaking Time for Surface Rough Milling](#). The default is 50% in aPriori starting point VPEs. Use the following option to override the default:
 - **User Override:** enter a whole number between 0 and 100, inclusive.

Pocket Rough Milling Options

Rough milling provides the following options:

- **Requested Percent Milled:** percent of the total pocket volume milled by the current occurrence of the roughing operation. Roughing on a given pocket has either one or two occurrences, depending on whether one or two tool diameters were selected for the pocket. When two diameters are chosen, there are two occurrences of roughing. In this case, part of the pocket's total volume is removed by the first occurrence, and the rest is removed by the second occurrence.

By default, the volume removed by the first operation occurrence is determined by linear interpolation—see [Chipmaking Time for Pocket Rough Milling](#). The volume removed by the second occurrence, by default, is the difference between the total pocket volume and the volume removed by the first occurrence.

You can override the default with this setup option.

- **Material Removal Rate:** rate at which material is removed during chipmaking. By default this is based on feed, speed, engagement width, and cut depth (see [Chipmaking Time for Pocket Rough Milling](#)). Use this option to override the default.
- **Tool Diameter:** diameter of the selected tool. Larger diameters can decrease engagement time—see [Chipmaking Time for Pocket Rough Milling](#)--and have a more favorable length-to-diameter ratio. Smaller diameters have better corner accessibility.

Diameter selection picks either one or two diameters for roughing a given pocket. If two diameters are chosen, two occurrences of the Rough Milling operation are associated with the pocket. The first occurrence uses the larger diameter to remove most of the pocket's volume, and the second occurrence uses the smaller diameter to remove the remaining volume.

By default, larger diameter is chosen to allow access to most of the part's volume, and the smaller diameter is chosen to allow the tool to fit into the pocket's corners. See [Diameter Selection for Pocket Roughing](#) for detailed information.

With this setup option, users can override default diameter selection for a particular occurrence of the Rough Milling operation.

- **Tool Cutting Speed:** how fast the tool turns in unit distance per unit time; that is, the speed at which a point on the outer edge of the tool moves along the circular path around the center of the tool. This value is used (along with feed, tool diameter, cut depth, and cut width) to determine volume removal rate. See [Tool Axis Speed](#) and [Chipmaking Time for Pocket Rough Milling](#) for more information on how speed contributes to cutting time.

Select one of the following options:

- **Use Recommended Tool Cutting Speed:** aPiori determines this value by interpolation from data tables based on tool series, tool type, tool diameter, and material cut code—see [Tool Selection](#). This value is adjusted to compensate for various factors, including machine spindle speed limitations and stock hardness. The value is also adjusted by multiplying by the cost model variable **millSpeedAdjustment**. The adjusted value is used to help determine volume removal rate.
- **Override Tool Cutting Speed:** enter a speed in meters per minute. This value is adjusted to compensate for various factors, including machine spindle speed limitations and stock hardness. The value is also adjusted by multiplying by the cost model variable **millSpeedAdjustment**, and a factor associated with the setup option **Rough Milling Aggression Adjustment Dial** (see [User Inputs for Machining](#)). The adjusted value is used to help determine volume removal rate.

See also [Feeds and Speeds in the Machining Cost Model](#).

- **Requested Feed per Tooth:** distance the tool travels along the surface of the part per tooth of the tool during one rotation. The number of tool teeth times this value is the distance the tool travels along the surface of the part per rotation of the tool. This value is used (along with speed, tool diameter cut width, and cut depth) to determine volume removal rate. See [Tool Axis Speed](#) and [Chipmaking Time for Pocket Rough Milling](#) for more information on how feed contributes to cutting time.

Select one of the following options:

- **Use Computed Feed per Tooth:** aPiori determines this value by interpolation from data tables based on tool series, tool diameter, and material cut code—see [Tool Selection](#). aPiori multiplies this value by the number of teeth to derive tool feed. This value is adjusted to compensate for various factors, including tool reach and required tolerance. Tool feed is also adjusted by multiplying by the cost model variable **millFeedAdjustment**. The adjusted value is used to help determine volume removal rate.
- **User Override:** enter a value in millimeters. aPiori multiplies this value by the number of teeth to derive tool feed. This value is adjusted to compensate for various factors, including tool reach and required tolerance. Tool feed is also adjusted by multiplying by the cost model variable **millFeedAdjustment**. The adjusted value is used to help determine volume removal rate.

See also [Feeds and Speeds in the Machining Cost Model](#).

- **Number of Teeth:** number of tool teeth. This value together with feed per tooth determines feed (which affects volume removal rate)—see [Tool Axis Speed](#) and [Chipmaking Time for Pocket Rough Milling](#).

Select one of the following options:

- **Number of teeth:** aPriori determines this value by interpolation from data tables based on tool series, tool diameter, and material cut code—see [Tool Selection](#). aPriori multiplies this value by the feed per tooth to derive tool feed. This value is adjusted to compensate for various factors, including tool reach and required tolerance. Tool feed is also adjusted by multiplying by the cost model variable **millFeedAdjustment**. The adjusted value is used to help determine volume removal rate.
- **User Override:** enter a value greater than or equal to 2.

If you supply a user override for both **Number of Teeth** and **Requested Feed per Tooth**, aPriori multiplies the two values together to derive tool feed.

If you supply a user override for **Number of Teeth**, and you do *not* specify a user override for **Requested Feed per Tooth**, aPriori sets the unadjusted value for feed as follows:

$$\text{Feed} = \text{Interpolated Feed} * (\text{Specified Number of Teeth} / \text{Interpolated Number of Teeth})$$

(Interpolated feed and interpolated number of teeth are derived from data tables during tool selection—see [Tool Selection](#).)

In either case, the value is adjusted to compensate for various factors, including tool reach and required tolerance. Tool feed is also adjusted by multiplying by the cost model variable **millFeedAdjustment**. The adjusted value is used to help determine volume removal rate.

- **Radial Cut Depth:** engagement length, either in millimeters or as a percentage of the tool diameter. This is the length along the tool radius of the area of contact between the part and the tool during chipmaking. Radial cut depth helps determine contact area and cut time. See [Chipmaking Time for Surface Rough Milling](#).

By default, radial cut depth is half the tool diameter.

Users can override the default with this setup option, by doing one of the following:

- Specify the radial cut depth in millimeters.
- Specify the radial cut depth as a percentage of the tool diameter.

- **Axial Cut Depth:** cut depth as a percentage of the tool diameter. This is the length along the tool axis of the area of contact between the part and the tool during chipmaking. Axial cut depth helps determine contact area and cut time. See [Chipmaking Time for Surface Rough Milling](#).

By default, axial cut depth is half the tool diameter. This value is adjusted based on machine power, and limited by the tool's maximum cutting depth and by pocket depth.

Users can override the default with this setup option, by doing one of the following:

- Specify the axial cut depth in millimeters.
- Specify the axial cut depth as a percentage of the tool diameter.

- **Tool Type:** either **Flat End Mill** or **Ball End Mill**. By default, ball end mills are chosen for the smaller (or only) tool when the pocket has one or more of the following:

- Matching wall and bottom fillet diameters
- Non-planar floor
- Walls that form an acute angle with the floor

See [Tool Type Selection for Pocket Rough Milling](#).

Users can override the default with this setup option.

Slot Milling Options

Slot Milling provides the following GCD-level options (the options apply to a specified slot):

- Tool Diameter
- Requested Number of Axial Passes
- Feed per Tooth
- Requested Num Teeth
- Tool Cutting Speed
- Axial Cut Depth

Tool Diameter

Diameter of the selected tool. By default this is the slot width. (It is the largest value in the lookup table **tblStandardToolSizes** that is less than or equal to the value of the **Width** property for the slot.) You can override the default with this option. Tool diameter can affect axial cut depth (see [Axial Cut Depth](#)), which can affect cycle time (see [Chipmaking Time for Slot Milling](#)).

Requested Number of Axial Passes

By default the number of axial passes is determined as follows:

- If the tool axis is parallel to the slot floor (see [Standard Slot Operations](#)), the number of passes is the sum of the geometric properties **End1 Length**, **Length**, and **End2 Length** divided by the axial cut depth (see [Axial Cut Depth](#)), rounded up to the nearest integer.
- Otherwise, the number of passes is the larger of the geometric properties **Depth A** and **Depth B** divided by the axial cut depth (see [Axial Cut Depth](#)), rounded up to the nearest integer.

Users can override the default with this option.

Feed per Tooth

Distance the tool travels along the surface of the part per tooth of the tool during one rotation. The number of tool teeth times this value is the distance the tool travels along the surface of the part per rotation of the tool. This value is used to help determine the tool axis speed. See [Tool Axis Speed](#) and [Chipmaking Time for Slot Milling](#) for more information.

Select one of the following options:

- **Use Computed Feed per Tooth:** aPiori determines this value by interpolation from data tables based on tool series, tool diameter, and material cut code—see [Tool](#)

Selection. aPriori multiplies this value by the number of teeth to derive tool feed. This value is adjusted to compensate for various factors, including tool reach and required tolerance. Tool feed is also adjusted by multiplying by the cost model variable **millFeedAdjustment**. The adjusted value is used to help determine tool axis speed.

- **User Override:** aPriori multiplies the value you enter by the number of teeth to derive tool feed. This value is adjusted to compensate for various factors, including tool reach and required tolerance. Tool feed is also adjusted by multiplying by the cost model variable **millFeedAdjustment**. The adjusted value is used to help determine tool axis speed.

See also [Feeds and Speeds in the Machining Cost Model](#).

Requested Num Teeth

Number of tool teeth. This value together with [Feed per Tooth](#) determines feed (which affects tool axis speed)—see [Tool Axis Speed](#) and [Chipmaking Time for Slot Milling](#).

Select one of the following options:

- **Number of teeth:** aPriori determines this value by interpolation from data tables based on tool series, tool diameter, and material cut code—see [Tool Selection](#). aPriori multiplies this value by the feed per tooth to derive tool feed. This value is adjusted to compensate for various factors, including tool reach and required tolerance. Tool feed is also adjusted by multiplying by the cost model variable **millFeedAdjustment**. The adjusted value is used to help determine tool axis speed.
- **User Override:** enter a value greater than or equal to 2.

If you supply a user override for both **Number of Teeth** and **Requested Feed per Tooth**, aPriori multiplies the two values together to derive tool feed.

If you supply a user override for **Number of Teeth**, and you do *not* specify a user override for **Requested Feed per Tooth**, aPriori sets the unadjusted value for feed as follows:

Feed = Interpolated Feed * (Specified Number of Teeth / Interpolated Number of Teeth)

(Interpolated feed and interpolated number of teeth are derived from data tables during tool selection—see [Tool Selection](#).)

In either case, the value is adjusted to compensate for various factors, including tool reach and required tolerance. Tool feed is also adjusted by multiplying by the cost model variable **millFeedAdjustment**. The adjusted value is used to help determine tool axis speed.

Tool Cutting Speed

How fast the tool turns in unit distance per unit time; that is, the speed at which a point on the outer edge of the tool moves along the circular path around the center of the tool. This value helps determine tool axis speed. See [Tool Axis Speed](#) and [Chipmaking Time for Slot Milling](#) for more information.

Select one of the following options:

- **Use Recommended Tool Cutting Speed:** aPriori determines this value by interpolation from data tables based on tool series, tool type, tool diameter, and material cut code—see [Tool Selection](#). This value is adjusted to compensate for various

factors, including machine spindle speed limitations and stock hardness. The value is also adjusted by multiplying by the cost model variable **millSpeedAdjustment**. The adjusted value is used to help determine tool axis speed.

- **Override Tool Cutting Speed:** enter a speed in meters per minute. This value is adjusted to compensate for various factors, including machine spindle speed limitations and stock hardness. The value is also adjusted by multiplying by the cost model variable **millSpeedAdjustment**, and a factor associated with the setup option **Rough Milling Aggression Adjustment Dial** (see [User Inputs for Machining](#)). The adjusted value is used to help determine tool axis speed.

See also [Feeds and Speeds in the Machining Cost Model](#).

Axial Cut Depth

Cut depth either in millimeters or as a percentage of the tool diameter. This is the length along the tool axis of the area of contact between the part and the tool during chipmaking. Axial cut depth helps determine the number of passes required to create the slot. See [Chipmaking Time for Slot Milling](#).

By default, axial cut depth is half the tool diameter.

Users can override the default, with this setup option, by doing one of the following:

- Specify the axial cut depth in millimeters.
- Specify the axial cut depth as a percentage of the tool diameter.

Groove Milling Options

Groove Milling provides the following GCD-level options (the options apply to a specified slot):

- Requested Tool Width
- Requested Number of Axial Passes
- Tool Diameter
- Requested Number of Radial Passes
- Feed per Tooth
- Requested Num Teeth
- Tool Cutting Speed
- Radial Cut Depth

Requested Tool Width

By default, tool width is slot width (the value of the geometric property **Width**), if a large enough tool can be found. Otherwise, default tool width is the **Max Tool Width**, looked up by groove depth and width in **tblGrooveMilling**, and adjusted by a factor looked up by tool series in **tblToolSeriesMultiplier**. Users can override the default with this option. Tool width affects cycle time—see [Chipmaking Time for Groove Milling](#).

Requested Number of Axial Passes

By default, this is the slot width (the value of the geometric property **Width**) divided by the tool width (see [Requested Tool Width](#)), rounded up to the nearest integer. Users can override the default with this setup option. The number of axial passes affects cycle time—see [Chipmaking Time for Groove Milling](#).

Tool Diameter

By default, tool diameter is looked up by groove depth and width in **tblGrooveMilling**, and adjusted by a factor looked up by tool series in **tblToolSeriesMultiplier**. Default tool diameter is also bounded above by the diameter of the tightest upward curve (pitch) in the slot floor (specified by the geometric property **Min Floor Diameter**). Users can override the default with this option. Tool diameter affects tool axis speed which affects cycle time—see [Tool Axis Speed](#) and [Chipmaking Time for Groove Milling](#).

Requested Number of Radial Passes

By default, this is the slot depth (the larger of the geometric properties **Depth A** and **Depth B**) divided by the **Radial Cut Depth**, rounded up to the nearest integer. Users can override the default with this setup option. The number of radial passes affects cycle time—see [Chipmaking Time for Groove Milling](#).

Feed per Tooth

Distance the tool travels along the surface of the part per tooth of the tool during one rotation. The number of tool teeth times this value is the distance the tool travels along the surface of the part per rotation of the tool. This value is used to help determine the tool axis speed. See [Tool Axis Speed](#) and [Chipmaking Time for Groove Milling](#) for more information.

Select one of the following options:

- **Use Computed Feed per Tooth:** aPiori determines this value by interpolation from data tables based on tool series, tool diameter, and material cut code—see [Tool Selection](#). aPiori multiplies this value by the number of teeth to derive tool feed. This value is adjusted to compensate for various factors, including tool reach and required tolerance. Tool feed is also adjusted by multiplying by the cost model variable **millFeedAdjustment**. The adjusted value is used to help determine tool axis speed.
- **User Override:** aPiori multiplies the value you enter by the number of teeth to derive tool feed. This value is adjusted to compensate for various factors, including tool reach and required tolerance. Tool feed is also adjusted by multiplying by the cost model variable **millFeedAdjustment**. The adjusted value is used to help determine tool axis speed.

See also [Feeds and Speeds in the Machining Cost Model](#).

Requested Num Teeth

Number of tool teeth. This value together with [Feed per Tooth](#) determines feed (which affects tool axis speed)—see [Tool Axis Speed](#) and [Chipmaking Time for Groove Milling](#).

Select one of the following options:

- **Number of teeth:** aPiori determines this value by interpolation from data tables based on tool series, tool diameter, and material cut code—see [Tool Selection](#).

aPriori multiplies this value by the feed per tooth to derive tool feed. This value is adjusted to compensate for various factors, including tool reach and required tolerance. Tool feed is also adjusted by multiplying by the cost model variable **millFeedAdjustment**. The adjusted value is used to help determine tool axis speed.

- **User Override:** enter a value greater than or equal to 2.

If you supply a user override for both **Number of Teeth** and **Requested Feed per Tooth**, aPriori multiplies the two values together to derive tool feed.

If you supply a user override for **Number of Teeth**, and you do *not* specify a user override for **Requested Feed per Tooth**, aPriori sets the unadjusted value for feed as follows:

Feed = Interpolated Feed * (Specified Number of Teeth / Interpolated Number of Teeth)

(Interpolated feed and interpolated number of teeth are derived from data tables during tool selection—see [Tool Selection](#).)

In either case, the value is adjusted to compensate for various factors, including tool reach and required tolerance. Tool feed is also adjusted by multiplying by the cost model variable **millFeedAdjustment**. The adjusted value is used to help determine tool axis speed.

Tool Cutting Speed

How fast the tool turns in unit distance per unit time; that is, the speed at which a point on the outer edge of the tool moves along the circular path around the center of the tool. This value helps determine tool axis speed. See [Tool Axis Speed](#) and [Chipmaking Time for Groove Milling](#) for more information.

Select one of the following options:

- **Use Recommended Tool Cutting Speed:** aPriori determines this value by interpolation from data tables based on tool series, tool type, tool diameter, and material cut code—see [Tool Selection](#). This value is adjusted to compensate for various factors, including machine spindle speed limitations and stock hardness. The value is also adjusted by multiplying by the cost model variable **millSpeedAdjustment**. The adjusted value is used to help determine tool axis speed.
- **Override Tool Cutting Speed:** enter a speed in meters per minute. This value is adjusted to compensate for various factors, including machine spindle speed limitations and stock hardness. The value is also adjusted by multiplying by the cost model variable **millSpeedAdjustment**, and a factor associated with the setup option **Rough Milling Aggression Adjustment Dial** (see [User Inputs for Machining](#)). The adjusted value is used to help determine tool axis speed.

See also [Feeds and Speeds in the Machining Cost Model](#).

Radial Cut Depth

Cut depth either in millimeters or as a percentage of the tool width. This is the length, along the depth of the slot, of the region of contact between the part and the tool during chipmaking. Radial cut depth helps determine the number of passes required to create the slot. See [Chipmaking Time for Groove Milling](#).

By default, radial cut depth is 25% of tool diameter for standard groove milling tools, and 45% of diameter for reduced shank groove mills. (Reduced shank groove mills have

20% lower feed and tool life than standard tools, and 20% higher cost—see the lookup table **tblToolSeriesMultipliers**.)

Users can override the default with this setup option, by doing one of the following:

- Specify the radial cut depth in millimeters.
- Specify the radial cut depth as a percentage of the tool width.

Slot Rough Milling Options

The Rough Milling operation for Slot GCDs provides the following GCD-level options (the options apply to a specified slot):

- Material Removal Rate
- Tool Diameter
- Tool Cutting Speed
- Number of Teeth
- Feed per Tooth
- Axial Cut Depth
- Radial Cut Depth

Material Removal Rate

Rate (volume per unit time) at which material is removed during chipmaking. By default this is based on feed, speed, engagement width, and cut depth (see [Chipmaking Time for Slot Rough Milling](#)). Use this option to override the default.

Tool Diameter

Diameter of the selected tool. Default tool diameter selection is described in [Diameter Selection for Slot Rough Milling](#). Use this option to override the default.

Tool Cutting Speed

How fast the tool turns in unit distance per unit time; that is, the speed at which a point on the outer edge of the tool moves along the circular path around the center of the tool. This value helps determine tool axis speed. See [Tool Axis Speed](#) and [Chipmaking Time for Slot Rough Milling](#) for more information.

Select one of the following options:

- **Use Recommended Tool Cutting Speed:** aPiori determines this value by interpolation from data tables based on tool series, tool type, tool diameter, and material cut code--see [Tool Selection](#). This value is adjusted to compensate for various factors, including machine spindle speed limitations and stock hardness. The value is also adjusted by multiplying by the cost model variable **millSpeedAdjustment**. The adjusted value is used to help determine tool axis speed.
- **Override Tool Cutting Speed:** enter a speed in meters per minute. This value is adjusted to compensate for various factors, including machine spindle speed limitations and stock hardness. The value is also adjusted by multiplying by the cost model variable **millSpeedAdjustment**, and a factor associated with the setup

option **Rough Milling Aggression Adjustment Dial** (see [User Inputs for Machining](#)). The adjusted value is used to help determine tool axis speed.

See also [Feeds and Speeds in the Machining Cost Model](#).

Number of Teeth

Number of tool teeth. This value together with [Feed per Tooth](#) determines feed (which affects tool axis speed)—see [Tool Axis Speed](#) and [Chipmaking Time for Slot Rough Milling](#).

Select one of the following options:

- **Number of teeth:** aPriori determines this value by interpolation from data tables based on tool series, tool diameter, and material cut code—see [Tool Selection](#). aPriori multiplies this value by the feed per tooth to derive tool feed. This value is adjusted to compensate for various factors, including tool reach and required tolerance. Tool feed is also adjusted by multiplying by the cost model variable **millFeedAdjustment**. The adjusted value is used to help determine tool axis speed.
- **User Override:** enter a value greater than or equal to 2.

If you supply a user override for both **Number of Teeth** and **Requested Feed per Tooth**, aPriori multiplies the two values together to derive tool feed.

If you supply a user override for **Number of Teeth**, and you do *not* specify a user override for **Requested Feed per Tooth**, aPriori sets the unadjusted value for feed as follows:

$$\text{Feed} = \text{Interpolated Feed} * (\text{Specified Number of Teeth} / \text{Interpolated Number of Teeth})$$

(Interpolated feed and interpolated number of teeth are derived from data tables during tool selection—see [Tool Selection](#).)

In either case, the value is adjusted to compensate for various factors, including tool reach and required tolerance. Tool feed is also adjusted by multiplying by the cost model variable **millFeedAdjustment**. The adjusted value is used to help determine tool axis speed.

Feed per Tooth

Distance the tool travels along the surface of the part per tooth of the tool during one rotation. The number of tool teeth times this value is the distance the tool travels along the surface of the part per rotation of the tool. This value is used to help determine the tool axis speed. See [Tool Axis Speed](#) and [Chipmaking Time for Slot Rough Milling](#) for more information.

Select one of the following options:

- **Use Computed Feed per Tooth:** aPriori determines this value by interpolation from data tables based on tool series, tool diameter, and material cut code—see [Tool Selection](#). aPriori multiplies this value by the number of teeth to derive tool feed. This value is adjusted to compensate for various factors, including tool reach and required tolerance. Tool feed is also adjusted by multiplying by the cost model variable **millFeedAdjustment**. The adjusted value is used to help determine tool axis speed.
- **User Override:** aPriori multiplies the value you enter by the number of teeth to derive tool feed. This value is adjusted to compensate for various factors,

including tool reach and required tolerance. Tool feed is also adjusted by multiplying by the cost model variable **millFeedAdjustment**. The adjusted value is used to help determine tool axis speed.

See also [Feeds and Speeds in the Machining Cost Model](#).

Axial Cut Depth

Cut depth either in millimeters or as a percentage of the tool diameter. This is the length along the tool axis of the area of contact between the part and the tool during chipmaking. Axial cut depth helps determine the rate at which material is removed to create the slot. See [Chipmaking Time for Slot Rough Milling](#).

By default, axial cut depth is half the tool diameter.

Users can override the default with this setup option, by doing one of the following:

- Specify the axial cut depth in millimeters.
- Specify the axial cut depth as a percentage of the tool diameter.

Radial Cut Depth

Cut depth either in millimeters or as a percentage of the tool diameter. This is the length, along the width of the slot, of the area of contact between the part and the tool during chipmaking. Radial cut depth helps determine the rate at which material is removed to create the slot. See [Chipmaking Time for Slot Rough Milling](#).

By default, radial cut depth is half the tool diameter.

Users can override the default with this setup option, by doing one of the following:

- Specify the radial cut depth in millimeters.
- Specify the radial cut depth as a percentage of the tool diameter.

Dovetail Finishing Options

The operation Finish Dovetail Milling provides the following GCD-level options (the options apply to a specified slot):

- **Cutting Method on First Pass:** by default in starting point VPEs, aPriori attempts to select a tool under the assumption that the tool will cut both sides of the roughed slot at once during the first finishing pass. If no such tool can be found, tool selection fails. This assumption generally allows selection of a larger, higher-speed tool (see [Diameter Selection for Dovetail Slot Finishing](#)), which significantly reduces cycle time (see [Feed, Speed, and Cut Time](#)).

VPE Administrators can change the default by setting the cost model variable **preferAggressiveDovetailCuttingMethod** to **false**. In this case, aPriori attempts to select a tool under the assumption that the tool will cut only one side of the roughed slot during the first finishing pass. If no such tool can be found, aPriori attempts to select a tool under the assumption that the tool will cut both sides of the roughed slot at once during the first finishing pass. If no such tool can be found, tool selection fails.

With this setup option, users can override the default for a given GCD. Check one of the following checkboxes:

- Let aPriori Decide: this is the default setting—see above.

- Conservative Method: in this case, aPiori attempts to select a tool under the assumption that the tool will cut only one side of the roughed slot during the first finishing pass. If no such tool can be found, tool selection fails.
- Aggressive Method: in this case, aPiori attempts to select a tool under the assumption that the tool will cut both sides of the roughed slot at once during the first finishing pass. If no such tool can be found, tool selection fails.

Note that the effect of this assumption on cycle time due to a reduction in the total number of passes required is negligible, because the feed rate must be reduced during a first pass that cuts both sides at once. But the effect on cycle time due to the use of a larger, higher-speed tool is significant.

- **Drop Hole Override:** for closed loop dovetail slots (see [Slot Properties](#)) the presence or absence of a drop hole affects tool selection. In general, the presence of a drop hole allows for selection of a larger, higher-speed tool (see [Diameter Selection for Dovetail Slot Finishing](#)), which can significantly reduce cycle time (see [Feed, Speed, and Cut Time](#)).

If a closed loop slot lacks a drop hole in the CAD model, this option allows the user to add a drop hole of a specified diameter, for the purposes of tool selection.

Select one of the following options:

- Drop Hole from 3D Geometry: this is the default. Tool selection assumes the presence of a drop hole only if one is modelled in the CAD.
- User Override: enter the drop hole diameter. This must be between the rough slot width (GCD property **Width**) and the width of the slot including undercuts (GCD property **Major Diameter**).

Note that this option has no effect on whether the operation Dovetail Edge Rounding is applied to the slot. If you specify the presence of a drop hole with this setup option, but no drop hole is modeled in the CAD, rounding is nevertheless applied when the slot has rounds (see [Dovetail Slot Operations](#)).

- **Requested Number of Radial Passes per Dovetail Side:** by default, the number of passes required per side for finishing is determined using a heuristic derived from a large, representative data sample. The heuristic represents the number of passes as a linear combination of tool neck diameter and slot depth (GCD property **Dovetail Depth A**). The number of passes impacts cycle time (see [Chipmaking Time for Finish Dovetail Milling](#)).

Users can override the default by selecting one of the following:

- Computed Number of Radial Passes: this is the default.
- User Override: enter the number of passes to assume for the purposes of calculating cycle time.

Note that overriding the default has no effect on tool selection; tool selection always assumes the number of passes given by the default heuristic (see [Diameter Selection for Dovetail Slot Finishing](#)).

- **Requested Feed per Tooth:** distance the tool travels along the surface of the part per tooth of the tool during one rotation. The number of tool teeth times this value is the distance the tool travels along the surface of the part per rotation of the tool. This value is used (along with speed and tool diameter) to determine tool axis speed. See [Tool Axis Speed](#).

Select one of the following options:

- **Use Computed Feed per Tooth:** aPriori determines this value by interpolation from data tables based on tool series, tool diameter, and material cut code—see [Tool Selection](#). aPriori multiplies this value by the number of teeth to derive tool feed. This value is adjusted to compensate for various factors, including tool reach and required tolerance. Tool feed is also adjusted by multiplying by the cost model variable **millFeedAdjustment**. The adjusted value is used to help determine tool axis speed.
- **User Override:** aPriori multiplies the value you enter by the number of teeth to derive tool feed. This value is adjusted to compensate for various factors, including tool reach and required tolerance. Tool feed is also adjusted by multiplying by the cost model variable **millFeedAdjustment**. The adjusted value is used to help determine tool axis speed.
- **Requested Number of Teeth on Tool:** number of tool teeth. This value together with feed per tooth determines feed (which affects tool axis speed)—see [Tool Axis Speed](#).

Select one of the following options:

- **Number of teeth:** aPriori determines this value by interpolation from data tables based on tool series, tool diameter, and material cut code—see [Tool Selection](#). aPriori multiplies this value by the feed per tooth to derive tool feed. This value is adjusted to compensate for various factors, including tool reach and required tolerance. Tool feed is also adjusted by multiplying by the cost model variable **millFeedAdjustment**. The adjusted value is used to help determine tool axis speed.
- **User Override:** enter a value greater than or equal to 2.

If you supply a user override for both **Number of Teeth** and **Requested Feed per Tooth**, aPriori multiplies the two values together to derive tool feed.

If you supply a user override for **Number of Teeth**, and you do *not* specify a user override for **Requested Feed per Tooth**, aPriori sets the unadjusted value for feed as follows:

$$\text{Feed} = \text{Interpolated Feed} * (\text{Specified Number of Teeth} / \text{Interpolated Number of Teeth})$$

(Interpolated feed and interpolated number of teeth are derived from data tables during tool selection—see [Tool Selection](#).)

In either case, the value is adjusted to compensate for various factors, including tool reach and required tolerance. Tool feed is also adjusted by multiplying by the cost model variable **millFeedAdjustment**. The adjusted value is used to help determine tool axis speed.

- **Requested Tool Cutting Speed:** how fast the tool turns in unit distance per unit time; that is, the speed at which a point on the outer edge of the tool moves along the circular path around the center of the tool. This value is used (along with feed and tool diameter) to determine tool axis speed. See [Tool Axis Speed](#).

Select one of the following options:

- **Use Recommended Tool Cutting Speed:** aPriori determines this value by interpolation from data tables based on tool series, tool diameter, and material cut code—see [Tool Selection](#). This value is adjusted to compensate for various factors, including machine spindle speed limitations and stock hardness. The value is also adjusted by multiplying by the cost model

- variable **millSpeedAdjustment**. The adjusted value is used to help determine tool axis speed.
- **Override Tool Cutting Speed:** enter a speed in meters per minute. This value is adjusted to compensate for various factors, including machine spindle speed limitations and stock hardness. The value is also adjusted by multiplying by the cost model variable **millSpeedAdjustment**. The adjusted value is used to help determine tool axis speed.
 - **Override Tool Dimensions:** By default, the tool diameter is chosen as described in [Diameter Selection for Dovetail Slot Finishing](#). With this option, users can override the default. Select one of the following options:
 - **Override Major Diameter:** enter the tool diameter (also known as the tool *major diameter*).
 - **Override Neck Diameter:** enter the tool neck diameter. The tool neck diameter is the difference between the tool major diameter and twice the slot undercut width (GCD property **Undercut Width A**).
 - **Tool Series:** the tools in the default tool series are *not* coated with titanium aluminum nitride (AlTiN). With this setup option, users can override the default, and direct aPiori to use a tool series whose tools are titanium coated, which extends tool life and performance. For titanium-coated tools:
 - Feed per tooth is 7.5% greater than tools that are not coated.
 - Tool cost is 7.0% greater.
 - Tool life is 10% greater.

Bulk Milling Options

BulkRemoval GCDs represent one or more general volumes that need to be removed from the stock to make a finished part. By default, aPiori assumes that the volume is removed by rough milling, and assigns one or more Bulk Milling operations for this purpose. To access these operations, navigate to the **BulkRemoval:1** GCD in the Geometric Cost Drivers pane, right-click and select **Edit Operation**. The Operation Sequence Selection window appears, displaying a node representing the machine performing the bulk milling operations (for example, 3 Axis Mill or 5 Axis Mill). Click + to expand the node and you will see one or more Bulk Milling operations, representing one or more roughing passes each performed with a particular tool diameter.

To see and adjust parameters of a Bulk Milling Operation, right-click one of these Bulk Milling operations and select **Process Setup Options**. The Process Setup Options window appears and displays characteristics of the operation, including chosen tool series and size, volume removed, and engagement time.

The following options allow you to adjust bulk milling parameters:

- **Request Percent Milled: percent of the volume to be allocated to the designated individual bulk milling operation.** By default, aPiori calculates this based on the geometric characteristics of the part, as well on the number of different tool diameters selected for bulk milling operations. **To override the default, use the following option:**
 - **Override Percent Milled:** enter a number between 0 and 100, inclusive.

- **Material Removal Rate:** rate at which material is removed during chipmaking. By default this is based on feed, speed, and volume to be removed (see [Chipmaking Time for Bulk Milling](#)). Use the following option to override the default:
 - **Override:** enter a value in cubic millimeters.
- **Requested Tool Diameter:** diameter of the selected tool. Larger diameters can decrease engagement time—see [Operation Cycle Time and Cut Time Calculations](#)--and have a more favorable length-to-diameter ratio. Smaller diameters have better corner accessibility.

Select one of the following options:

- **Use Computed Tool Diameter:** aPiori chooses a tool diameter based on a number of factors, including overall part size, accessibility of the GCD's corners (if any), and the values of setup options that constrain tool size. See [Tool Selection](#) for more information.
 - **Override Tool Diameter:** enter the tool diameter in millimeters.
- **Requested Tool Cutting Speed:** how fast the tool turns in unit distance per unit time; that is, the speed at which a point on the outer edge of the tool moves along the circular path around the center of the tool. This value is used (along with feed, tool diameter, and cutting width) to determine area removal rate. See [Operation Cycle Time and Cut Time Calculations](#) for more information on how speed contributes to cutting time.

Select one of the following options:

- **Use Recommended Tool Cutting Speed:** aPiori determines this value by interpolation from data tables based on tool series, tool diameter, and material cut code--see [Tool Selection](#). This value is adjusted to compensate for various factors, including machine spindle speed limitations and stock hardness. The value is also adjusted by multiplying by the cost model variable `millSpeedAdjustment`. The adjusted value is used to help determine area removal rate.
 - **Override Tool Cutting Speed:** enter a speed in meters per minute. This value is adjusted to compensate for various factors, including machine spindle speed limitations and stock hardness. The value is also adjusted by multiplying by the cost model variable `millSpeedAdjustment`. The adjusted value is used to help determine area removal rate.
- **Requested Feed per Tooth:** distance the tool travels along the surface of the part per tooth of the tool during one rotation. The number of tool teeth times this value is the distance the tool travels along the surface of the part per rotation of the tool. This value is used (along with speed, tool diameter and cutting width) to determine area removal rate. See [Operation Cycle Time and Cut Time Calculations](#) for more information on how feed contributes to cutting time.

Select one of the following options:

- **Use Computed Feed per Tooth:** aPiori determines this value by interpolation from data tables based on tool series, tool diameter, and material cut code—see [Tool Selection](#). aPiori multiplies this value by the number of teeth to derive tool feed. This value is adjusted to compensate for various factors, including tool reach and required tolerance. Tool feed is also adjusted by multiplying by the cost model variable `millFeedAdjustment`. The adjusted value is used to help determine area removal rate.

- **User Override:** aPiori multiplies the value you enter by the number of teeth to derive tool feed. This value is adjusted to compensate for various factors, including tool reach and required tolerance. Tool feed is also adjusted by multiplying by the cost model variable **millFeedAdjustment**. The adjusted value is used to help determine area removal rate.
- **Number of Teeth:** number of tool teeth. This value together with feed per tooth determines feed (which affects area removal rate)—see [Operation Cycle Time and Cut Time Calculations](#).

Select one of the following options:

- **Number of teeth:** aPiori determines this value by interpolation from data tables based on tool series, tool diameter, and material cut code—see [Tool Selection](#). aPiori multiplies this value by the feed per tooth to derive tool feed. This value is adjusted to compensate for various factors, including tool reach and required tolerance. Tool feed is also adjusted by multiplying by the cost model variable **millFeedAdjustment**. The adjusted value is used to help determine area removal rate.
- **User Override:** enter a value greater than or equal to 2.

If you supply a user override for both **Number of Teeth** and **Requested Feed per Tooth**, aPiori multiplies the two values together to derive tool feed.

If you supply a user override for **Number of Teeth**, and you do *not* specify a user override for **Requested Feed per Tooth**, aPiori sets the unadjusted value for feed as follows:

$$\text{Feed} = \text{Interpolated Feed} * (\text{Specified Number of Teeth} / \text{Interpolated Number of Teeth})$$

(Interpolated feed and interpolated number of teeth are derived from data tables during tool selection—see [Tool Selection](#).)

In either case, the value is adjusted to compensate for various factors, including tool reach and required tolerance. Tool feed is also adjusted by multiplying by the cost model variable **millFeedAdjustment**. The adjusted value is used to help determine area removal rate.

- **Radial Cut Depth:** engagement length as a percentage of the tool diameter. Radial cut depth helps determine contact area and cut time. See [Chipmaking Time for Bulk Milling](#). The default is 50% in aPiori starting point VPEs. Use the following option to override the default:
 - **User Override:** enter a whole number between 0 and 100, inclusive.
- **Axial Cut Depth:** cut depth as a percentage of the tool diameter. Axial cut depth helps determine contact area and cut time. See [Chipmaking Time for Bulk Milling](#). The default is 50% in aPiori starting point VPEs. Use the following option to override the default:
 - **User Override:** enter a whole number between 0 and 100, inclusive.
- **Dropoff Volume:** (Bulk Milling only) volume removed by an alternative process such as Wire EDM rather than a rough milling process. (To access this option, by right-click the *top-most* Bulk Milling node in the Manufacturing Process pane and select Process Setup Options.)

This defaults to 0. If you override the default, be sure to manually assign Wire EDM to the wired surfaces in order to account for Wire EDM cycle times and costs.

Use this option to override the default:

- **Dropoff Volume:** enter a value in cubic millimeters.

Keyway Broaching Options

The Broach process provides the following options:

- **Batch Setup Time:** total setup time for a batch. This time is attributed to individual parts by dividing the batch setup time by the batch size specified on the **Production Info** tab of the **Cost Object** window.
 - **Use default value:** the default is specified by the machine property **Setup Time**.
 - **User Override:** specify a value in hours to override the default.
- **Fixture Cost:** contributes to total amortized investment.
 - **Use default value:** the default is the product of the machine properties **Fixture Build Rate** and **Fixture Build Time**.
 - **User Override:** specify a cost to override the default.

Keyway broaching operations provide the following options:

- **Shims** (Multipass Keyway Broaching only): number of shims used to make the keyway.
 - **Default Value:** one less than the calculated number of broaching passes (see [Cycle Time for Machining Operations](#)).
 - **User Value:** enter the number of shims. Cycle time increases with the number of shims. Note that the number of broaching passes is one more than the number of shims, since the first pass doesn't use a shim.
- **Passes** (Single Pass Keyway Broaching only): number of broaching passes performed to make the keyway.
 - **Default Value:** calculated as described in [Cycle Time for Machining Operations](#).
 - **User Value:** enter the number of passes. Cycle time increases with the number of passes.
- **Cutting Speed:** linear cutting speed of the broach in the pull direction.
 - **Default:** By default this is specified by a tool property (see [Tool Selection for Keyway Broaching](#)) and potentially adjusted as described in [Cycle Time for Machining Operations](#).
 - **User:** enter the cutting speed. Cycle time decreases as cutting speed increases.
- **Pitch:** distance between the broach's teeth.
 - **Default Value:** specified by a tool property (see [Tool Selection for Keyway Broaching](#)).
 - **User Value:** enter the tooth pitch. Increasing tooth pitch effectively increases cutting length, which increases cutting time per pass—see [Cycle Time for Machining Operations](#).

- **Teeth:** number of teeth on the broach.
 - Default Value: specified by a tool property (see [Tool Selection for Keyway Broaching](#)).
 - User Value: enter the number of tool teeth. Increasing the number of teeth effectively increases cutting length, which increases cutting time per pass; but it also increases cutting depth per pass, which might decrease the number of passes required—see [Cycle Time for Machining Operations](#).
- **Feed per Tooth:** depth of material removed (in the keyway depth direction) per tooth, per pass.
 - Default Value: specified by a tool property (see [Tool Selection for Keyway Broaching](#)).
 - User Value: enter the feed per tooth. Increasing feed per tooth increases depth per pass, which can decrease cycle time—see [Cycle Time for Machining Operations](#).
- **Repositioning Time:** time to position the broach before each pass.
 - Default Value: specified by the plant variable **multiPassKeywayBroachingPositioningTime** or **singlePassKeywayBroachingPositioningTime**.
 - User Value: enter the repositioning time. Total handling time is repositioning time multiplied by the number of passes. Increasing repositioning time increases handling time, which increases cycle time—see [Cycle Time for Machining Operations](#).

Chemical Milling Options

This section covers the following setup options:

- Bench Operation Options
- Mask Spray
- Mask Cure Options
- Scribe Option
- Etch Cell Options

Bench Operation Options

The child operations of the Bench Operation process provide the following setup options:

- **Final inspection time:** defined on the Final Inspecting operation. By default, final inspection time is specified by the cost model variable **defaultFinalInspectionTime** (5 minutes in starting point VPEs). Users can override the default on a part-by-part basis with this setup option.
- **Identing Time:** defined on the Identing operation. By default, ident time is specified by the cost model variable **defaultIdentingTime** (45 seconds in starting point VPEs). Users can override the default on a part-by-part basis with this setup option.
- **Spark Test Time:** defined on the Spark Testing operation. By default, spark test time is specified by the cost model variable **defaultSparkTestTime** (2 minutes in starting point VPEs). Users can override the default on a part-by-part basis with this setup option.

Mask Spray Options

See [Mask Spray Inputs](#) in the Surface Treatment chapter of this Guide.

Mask Cure Options

The Mask Cure process provides the following setup option:

- **Select maskant material used:** by default, masking material is specified by the first entry of the lookup table **tblMaskingMaterials**. Users can override the default on a part-by-part basis with this setup option.
- **Heated cure cycle:** by default, the cure cycle is assumed to be heated. Users can override the default on a part-by-part basis with this setup option.

Scribe Option

The Scribe process provides the following setup option:

- **Programming Cost:** by default, programming cost is the product of the machine properties **Programming Rate** and **Programming Time**. With this setup option, users can override the default on a part-by-part basis, and specify the programming cost explicitly.

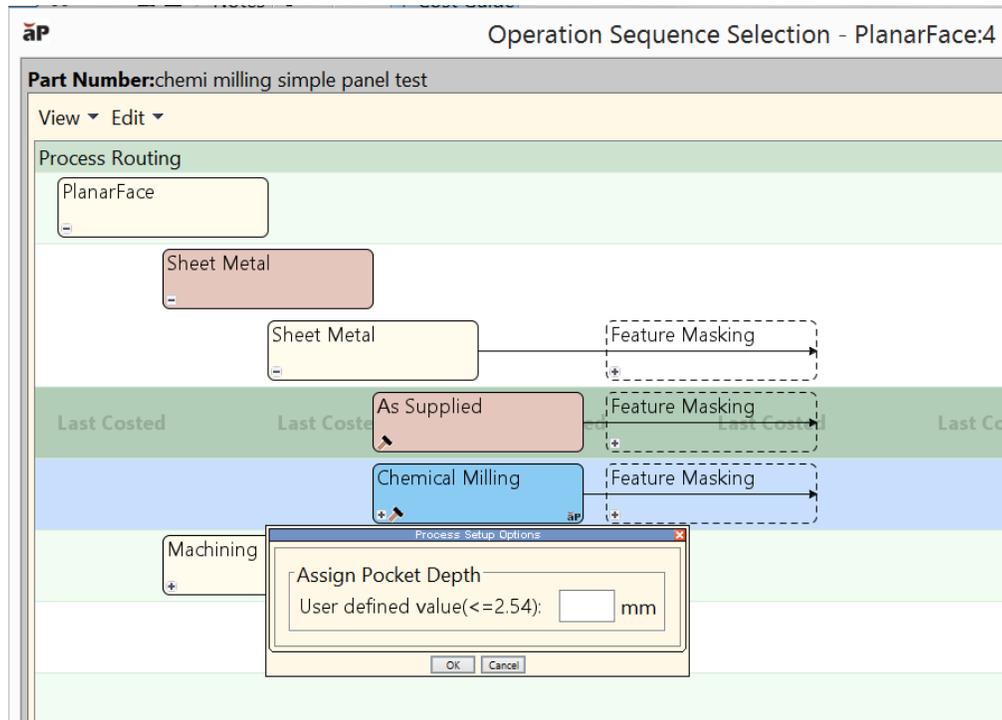
Etch Cell Options

The Etch Cell Cycle component-level operation provides the following setup option:

- **Chemical Etch Rate:** by default, the etch rate (see [Etch Cell Formulas](#)) is specified by the cost model variable **defaultChemicalEtchingRate** (0.0381mm/minute in starting point VPEs). Users can override the default on a part-by-part or etch-cell-by-etch-cell basis with this setup option.

If you edit a surface's operation sequence in order to assign Chemical Milling to it, you can use the following GCD-level setup option to specify the depth to which the surface is to be etched:

- **Assign Pocket Depth:** enter the depth to which the surface is to be etched. This affects etching cycle time, as well as the arrangement of pockets into etch cell cycles. See [Etch Cell Formulas](#).



If you don't enter an etch depth, the cost model uses the depth of the shallowest form of type STAMP, if there is one; otherwise, the cost model uses 50% of the blank thickness.

Setup Operation Options

For most machining processes, aPiori automatically computes the number of part setups, or specific orientations that the part must be placed in, that are required to perform the assigned operations on that machine. For more information, see [Working with Part Setups and SetupAxis GCDs](#). You can provide additional information about part setups using the following process options:

- **Repetitions of part setup:** number of repetitions of the setup procedure for each orientation. By default, aPiori assumes that a part is setup only once in each orientation. However, you can use this option to override this assumption and specify if the part is actually setup multiple times in a given orientation. This may occur, for example, if the routing sheet indicates that some features of the part are machined, then the part is removed for inspection of the feature, and then placed back on the machine in the same orientation to machine additional features. Use the following option:
 - Default Repetitions of Part Setup: the value of the cost model variable **repetitionsOfPartSetup**, which is 1 in aPiori baselines.
 - Override Repetitions of Part Setup: enter a positive whole number, the number of times the setup procedure is performed for the current part orientation.
- **Total setup time:** time to perform a single given setup. By default, aPiori computes the time required for each part setup based on the part weight, including the time for cleaning, loading, clamping and orienting the part. This process setup option allows you to override the time required for the specified setup.

To override the amount of time required for a specific setup, expand the manufacturing process of interest (e.g., 3-Axis Mill), right-click on the Setup node of interest, and select Process Setup Options.

Material Stock Options

For a discussion on the purpose of material stock allowances, see [Stock Machining Material Stock Allowances](#).

To override the default stock allowances specified for your machining VPE, edit setup options defined on the Material Stock routing node (right-click on the Material Stock node in the Manufacturing Process pane, and select Process Setup Options, or else select the Material Stock node in the Process and Machine Options tab of the Cost Guide, and click Set Process Options or Machine). There are options that allow you to override the allowance, or offset amount, in a specified direction:

- **OD Stock Dimension:** specify the minimum allowance for the Outer Diameter of the part, or the total Outside Diameter. Applies to round bar and round tube stock only.
- **ID Stock Allowance:** specify the minimum allowance for the Inner Diameter of the part, or the total Inner Diameter. Applies to round tube stock only.
- **Stock Length Dimension:** specify the minimum allowance for the length direction of the stock, or the total length. Applies to bar stock only.
- **Stock Width Dimension:** specify the minimum allowance for the width direction of the stock, or the total width. Applies to square and rectangular bar stock only.
- **Stock Height Dimension:** specify the minimum allowance for the height direction of the stock, or the total height. Applies to square and rectangular bar stock only.
- **Plate Part Nest Length:** specify the minimum allowance for the length direction of the stock, or the total length. Applies to plate stock only.
- **Plate Part Nest Width:** specify the minimum allowance for the width direction of the stock, or the total width. Applies to plate stock only.
- **Plate Thickness:** specify the minimum allowance for the height direction of the stock, or the total thickness. Applies to plate stock only.

The length direction of the stock is the direction that is perpendicular to the recognized cross-section, which can be displayed by clicking the  Stock Form and Alignment button in the Component Viewer tool bar. For parts with rectangular stock, by default the height direction is along the smaller side of the cross-section and the width direction is along the longer side, although this can be modified using the Stock Form and Alignment window.

The Material Stock routing node also provides the following options:

- **Plate Stock Length:** applies to plate stock only.
- **Plate Stock Width:** applies to plate stock only.
- **Perimeter Cutting Leadin Amount:** applies to plate stock only.
- **Rectangular Nesting Part Orientation:** applies to plate stock only.
- **Snap Up to a Standard Stock Height:** applies to plate, rectangular bar, and round bar stock only. This setup option specifies how aPriori selects stock thickness. By

default, in starting point VPEs, aPriori selects actual stock with the smallest standard thickness greater than or equal to the ideal thickness for the part (see [Stock Machining Material Stock Allowances](#)), and only selects virtual stock if there is no such actual stock. With this option, you can override the default on a part-by-part basis. Select one of the following options:

- True: select actual stock with the smallest standard thickness greater than or equal to the ideal thickness (or select virtual stock, if there is no such actual stock). The setup option Stock Unit System determines whether aPriori uses metric standard stock heights or US standard stock heights.
- False: select virtual stock if there is no actual stock with ideal thickness.

VPE administrators can change a VPE's default stock-selection behavior with the cost model variable **snapStockSize** (which is **true** in aPriori starting point VPEs).

- **Stock Unit System:** determines whether to use metric standard stock height or US standard stock height, when stock selection snaps up to standard height (see the setup option Snap Up to a Standard Stock Height, above).

Design-to-cost Configuration for Machining

With the Machining process group, you can configure some of the data that helps determine which issues are listed in the **Design to Cost** tab. This data is contained in lookup tables, and affects issues related to non-standard tool diameters and specialized finishing operations.

Holes and Fillets		
Distinct hole diameters	8	Review 
Distinct indirect fillet radii	4	
Non-standard tools	6	

Tolerances and Finishing Operations		
GCDs with tolerances	478	Review 
GCDs with specialized finishing	0	

Lookup tables related to non-standard tool diameters are covered in the following sections:

- Standard Drilling Tool Diameters
- Standard Filleting Tool Diameters

A lookup table related to tolerances and specialized finishing operations is covered in [Tolerance Grade and Roughness Ranges](#).

Standard Drilling Tool Diameters

The lookup table **tblDrillSizeChart** lists sizes that are considered to be standard diameters for drilling tools.

Drill Size (mm)	Drill Size Name
0.05	#107
0.05	0.05 mm
0.06	#106
0.07	#105
0.08	#104
0.09	#103
0.10	#102
0.10	0.1 mm
0.11	#101

When a hole has a non-standard diameter (and so requires a non-standard tool), it is listed in the Holes and Fillets dialog (click Review in the Holes and Fillets section of the Design to Cost tab).

Non-standard tools and using many unique tools can increase manufacturing complexity and cost. Try to minimize the number of unique and non-standard hole diameters and fillet radii within the component. Select type or size to show associated GCDs in viewer

Type/Size	Tool Count	GCD Count	Tools (mm)/GCDs	GCD Count
Hole - Standard	3	15	3.5052	2
Hole - Non-Standard	5	11	SimpleHole:13	
			SimpleHole:14	
Fillet Radius - Standard	3	23	3.81	1
Fillet Radius - Non-Standard	1	6	SimpleHole:23	
			3.9624	2
			SimpleHole:3	
			SimpleHole:2	
			14.605	4
			SimpleHole:22	

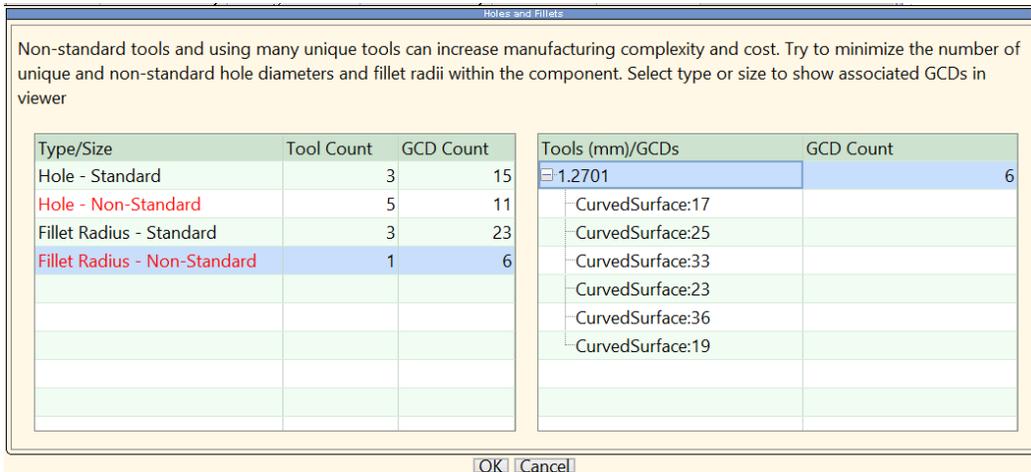
[OK] [Cancel]

Standard Filleting Tool Diameters

The lookup table `tblPreferredSizes` lists sizes that are considered to be standard diameters for milling and roughing tools.

Unit System	Size
both	0.20000
both	0.25400
both	0.30000
both	0.30480
both	0.38100
both	0.40000
both	0.45720
both	0.50000
both	0.50800
both	0.55880

When a fillet requires a non-standard tool diameter, it is listed in the Holes and Fillets dialog (click Review in the Holes and Fillets section of the Design to Cost tab).



Tolerance Grade and Roughness Ranges

The lookup table `tblGtolProcessCapabilities` lists the geometric tolerance grade and roughness ranges achievable by a given process for a given type of tolerance/roughness. A tolerance grade range together with a feature size determines a literal tolerance range. See the section “How aPiori calculates achievable tolerance ranges” in the *aPiori Professional User Guide*.

Process	Gtol Category	Capability System	Best Achievable	Worst Achievable	Num Repetitions
3D Laser	angularity	IT	10	16	1.00
3D Laser	bendAngleTolerance	IT	10	16	1.00
3D Laser	circularity	IT	10	16	1.00
3D Laser	concentricity	IT	10	16	1.00
3D Laser	cylindricity	IT	10	16	1.00
3D Laser	diamTolerance	IT	10	16	1.00
3D Laser	flatness	IT	10	16	1.00
3D Laser	parallelism	IT	10	16	1.00
3D Laser	perpendicularity	IT	10	16	1.00
3D Laser	positionTolerance	IT	10	16	1.00

Tolerance and roughness ranges affect cycle times, and help determine which features require specialized finishing operations. See the Tolerances and Finishing Operations section of the Design to Cost tab.

Semi-automated Costing

When you use aPiori, your workflow is typically iterative: you cost a part, examine the results, modify inputs (such as production information, process setup options, or part geometry), and then repeat the process. For the machining process group, advanced users can incorporate the use of aPiori’s diagnostic tools into this iterative workflow, including aPiori’s Heat Map and Features to Review listing.

This section contains the following subsections:

- Semi-automated Costing
- Diagnostic Information
- Workflow
- Achieving Full Costing

Semi-automated Costing

There are two alternative versions of this advanced workflow, one that uses fully automated costing and one that uses semi-automated costing.

Semi-automated costing is for more experienced users, and is restricted to the 3-Axis Mill process. During semi-automated costing, aPriori is less aggressive in attempting to assign operations to GCDs, which sometimes results in only partial costing of the current part, especially in earlier iterations of the workflow. Semi-automated costing automatically assigns only relatively easy-to-perform, efficient operations to each GCD, using only principal and user-activated setup axes (see [Working with Part Setups and SetupAxis GCDs](#)).

GCDs that can't be assigned an operation under these constraints are not costed and are classified as features to review (they are assigned to the special classification, Features to Review in the Manufacturing Process pane). For example, aPriori does not assign contouring to large surfaces during semi-automated costing (where the large-surface threshold can be specified by a process setup option). A surface too large for contouring is assigned to Features to Review.

Features to Review serves as a to-do list for achieving full costing. For each feature to review; you must take action, either by manually assigning an operation to the feature, or by modifying setup options, setup axes, or part geometry in order to make an operation feasible for auto-assignment.

During fully automated costing, aPriori aggressively tries to assign operations to each GCD, even if it means using relatively more setup axes and assigning relatively difficult, less efficient operations. In this mode, GCDs that cannot be otherwise assigned a finishing operation are assigned General Mill Finishing.

Diagnostic Information

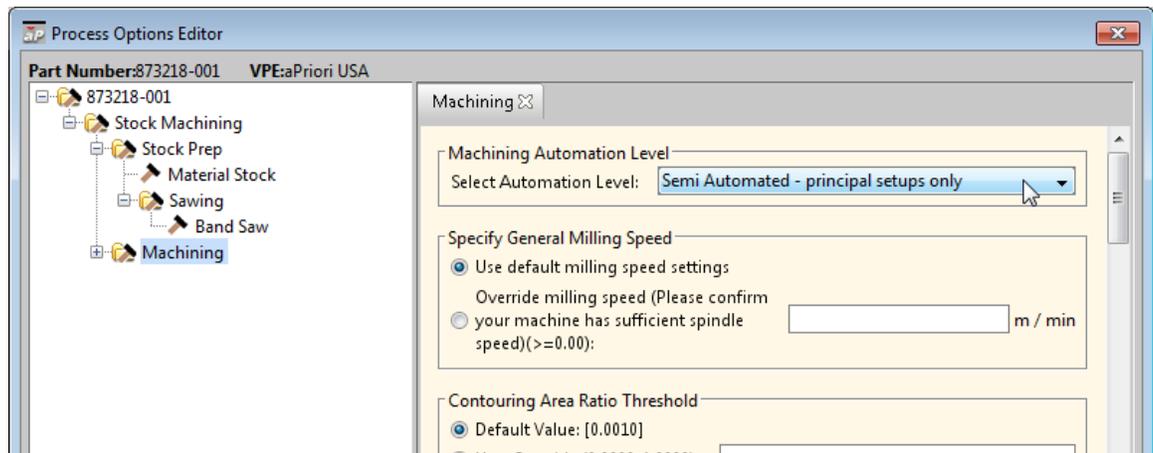
For each GCD that is assigned to Features to Review or General Mill Finishing, aPriori provides diagnostic information, including information on why each other candidate operation was considered infeasible. Diagnostic information, for example, can indicate that facing was considered infeasible because no principal or user-activated setup would render the GCD accessible for facing, and contouring was considered infeasible because the surface was too large. This information can guide your modification of operation assignments, process setup options, setup axes, or part geometry. See [Working with Features to Review](#) for more information.

aPriori's Heat Map facility provides an additional diagnostic aid. You can direct aPriori to display your part in the Viewer in the form of a heat map. Each of the part's GCDs is filled in with a color that indicates the value range, for the GCD, of a specified metric, such as cycle time, area removal rate, or tool diameter. Warmer colors (such as red or orange) generally indicate potential problems. As with the diagnostic information for Features to Review, the heat map can lead you to modify process setup options, setup axes, or operation assignments. The heat map also has a mode in which it displays features to review, with the color indicating the feature's importance. See [Working with the Heat Map](#) for more information.

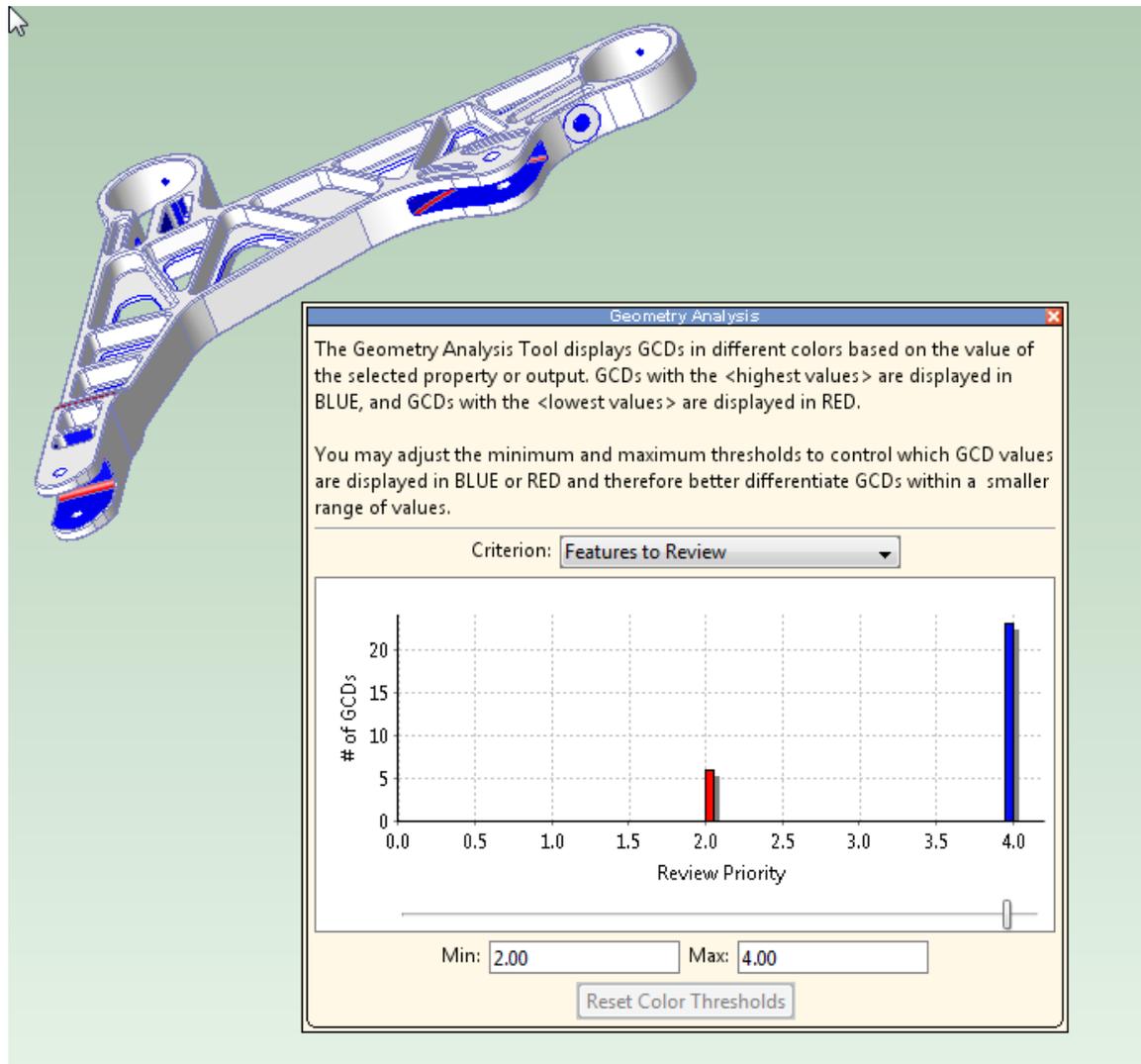
Workflow

Here is a typical workflow using semi-automated costing:

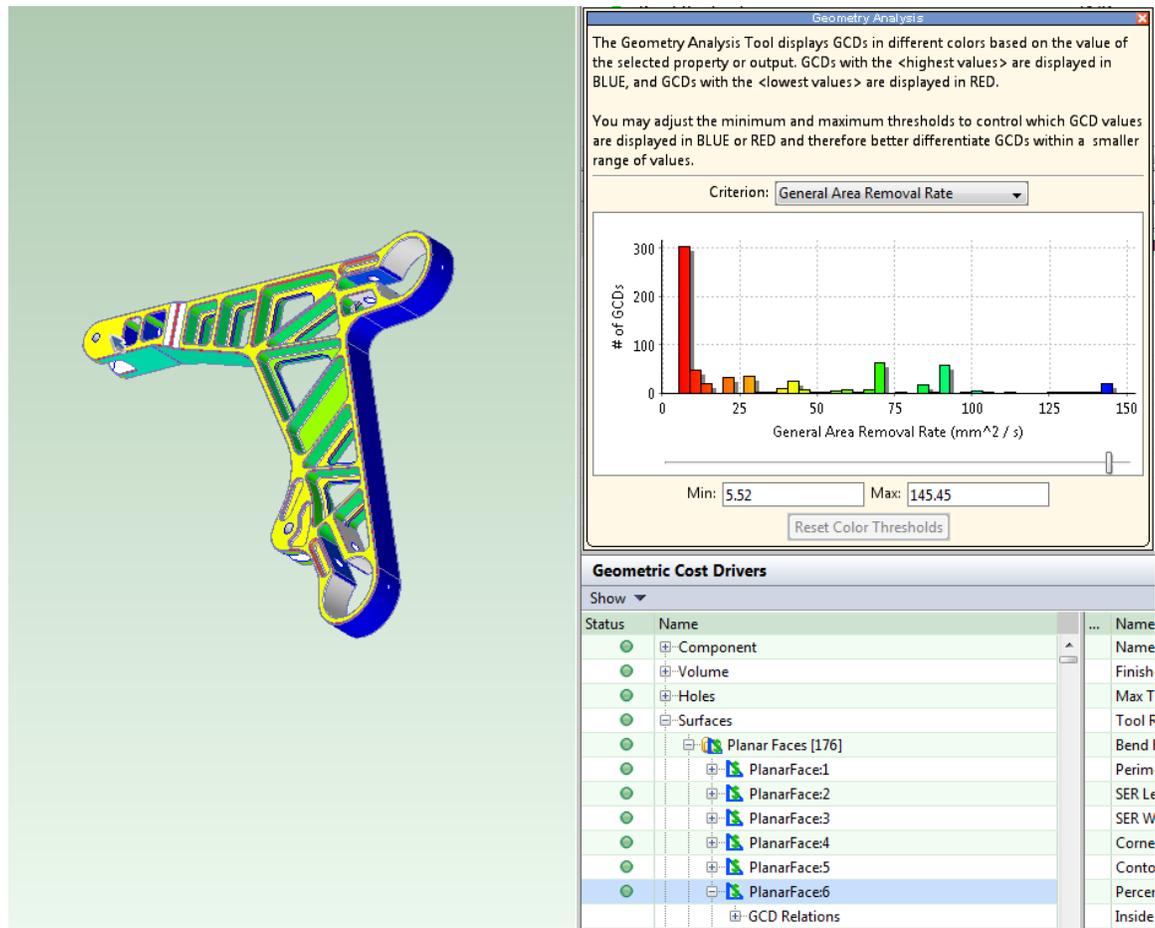
- 1 **Set automation level and cost part:** set the process setup option **Machining Automation Level** to **Semi-Automated**, and **Cost** your part.



- 2 **Examine principal setup axes:** examine the setup axes activated by aPriori (rotate the part to assess how axes are oriented with respect to the various GCDs). Consider whether you should override aPriori's choice of principal setup axes—see [Principal Setup Axes](#).
- 3 **Examine features to review:** examine the Heat Map for the **Features to Review** category. The GCDs shown in warmer colors are the more important ones—larger or more complex surfaces, potentially contoured surfaces, or deep holes or side walls.



- 4 **Take action to achieve full costing:** Go through each GCD listed under Features to Review, in order of importance, and take action to effect an operation assignment for the GC; and then cost the part again. Do this until there are no more GCDs classified under Features to Review, and all GCDs cost successfully. See [Achieving Full Costing](#) for the sub-steps of this step.
- 5 **Examine contoured surfaces:** examine the Heat Map for **Contouring Area Removal Rate**. GCDs assigned to contouring are shown in the Viewer. For problem GCDs, such as those whose removal rate is too slow (those with a warm color, such as red or orange), consider whether to modify setup options, such as those for feed, speed, or tool diameter, or effect an assignment of side milling or facing, and then re-cost if you made changes. See [Contouring Area Removal Rate](#) in [Working with the Heat Map](#).
- 6 **Examine area removal rates for other GCDs:** examine the Heat Map for **General Area Removal Rate**, **Cycle Time**, and other metrics. For GCDs whose removal rate is too slow, consider whether to modify setup options, such as those for feed, speed, or tool diameter, or effect a different operation assignment, and then re-cost if you made changes. See [Working with the Heat Map](#).

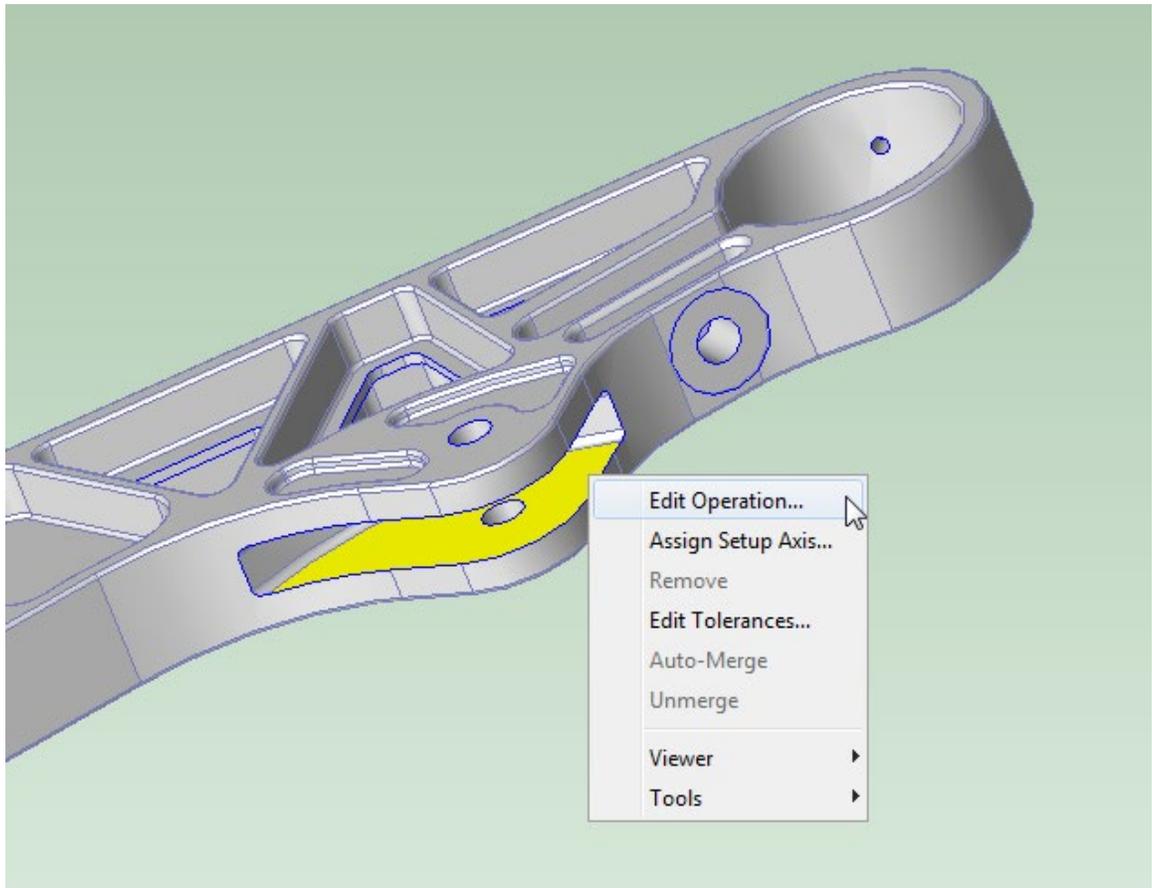


A typical workflow for fully automated costing is similar; but with fully automated costing you examine features assigned to General Mill Finishing instead of Features to Review. You can still use the diagnostic information to help you effect alternative operation assignments where appropriate, but this is not required in order to achieve full costing, as it is with semi-automated costing.

Achieving Full Costing

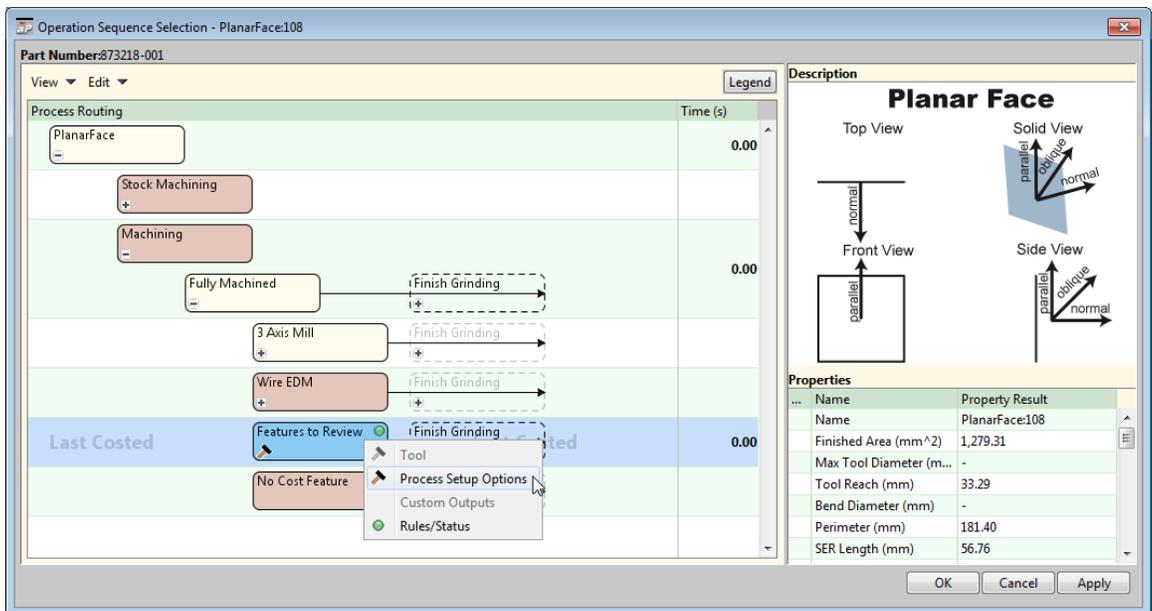
When you use semi-automated costing, your part might be only partially costing. To achieve full costing, follow these steps:

- 1 In the Viewer, select the most important (remaining) GCD to review. Click the GCD to select it (the GCD turns yellow when selected).
- 2 Right-click the selected GCD, and select **Edit Operation...**

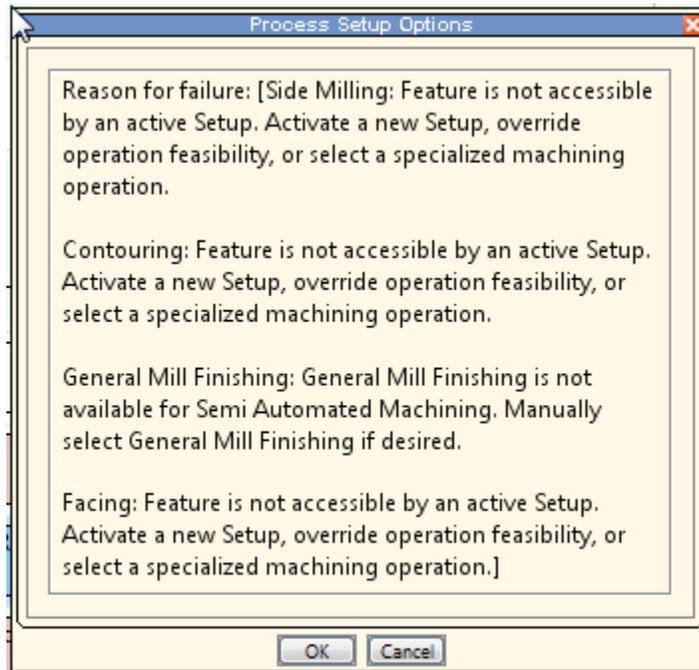


The Operation Sequence Selection dialog appears.

- 3 In the Operation Sequence Selection dialog, right-click the Features to Review rectangle, and select **Process Setup Options**.



Diagnostic information appears, listing the reasons for the infeasibility of candidate operations.



- 4 Take action to effect an operation assignment, based on the diagnostic information. Here are some examples of reasons for the infeasibility of candidate operations, together with appropriate responses:
 - Walls adjacent to the GCD form a sharp corner. Consider whether you should activate a setup axis to allow facing, or (if sharp corners are not the intended geometry) modify the CAD model.
 - Feature is not accessible from any available setup axis (see [Working with Part Setups and SetupAxis GCDs](#)). Consider activating an additional setup axis or overriding the principal setup axes.
 - Feature has an undercut. Consider manually assigning an appropriate operation (such as Undercut Milling). See [Manually Assigned Operations](#).
 - Surface too large for contouring. Consider modifying the contouring area ratio threshold. See [Contouring Area Ratio Threshold](#) in [Machining Node Process Setup Options](#).
- 5 Cost the part again, and check for the desired operation assignment.
- 6 If other GCDs are listed as Features to Review, go back to step 1.

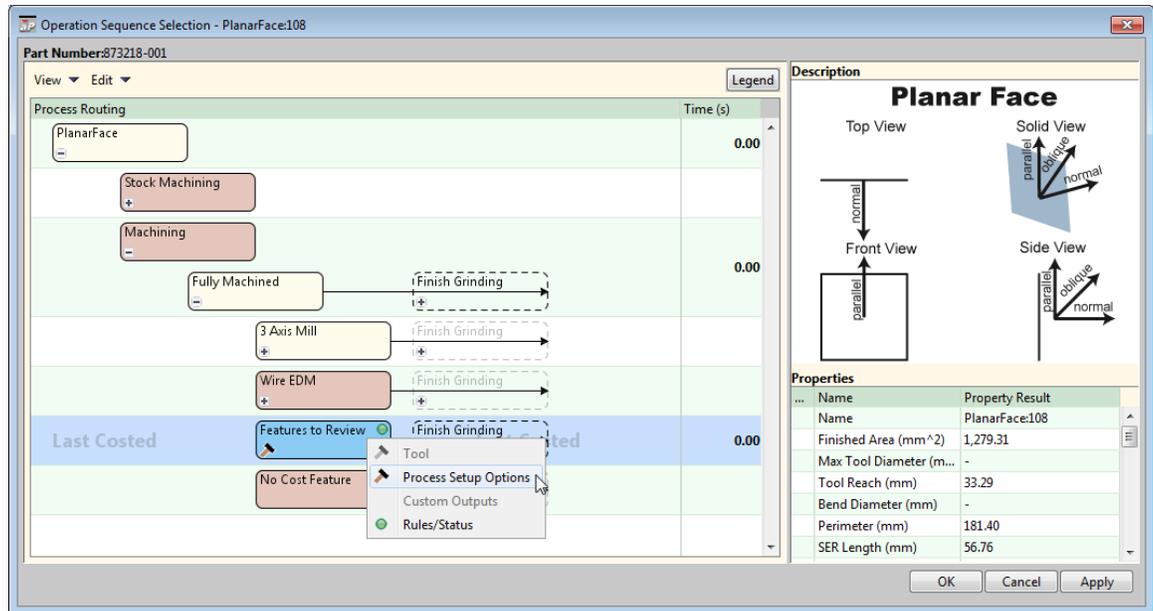
Working with Features to Review

You can examine GCDs assigned to Features to Review or General Mill Finishing to obtain diagnostic information, including the reasons for the infeasibility of operations that were considered (but rejected) for the GCD.

When you use semi-automated costing, Features to Review serves as a to-do list for achieving full costing. For each feature to review; you must take action, either by manually assigning an operation to the feature, or by modifying setup options, setup axes, or part geometry in order to make an operation feasible for auto-assignment (see [Semi-automated Costing](#)).

Follow these steps to examine GCDs assigned to Features to Review or General Mill Finishing:

- 1 In the Manufacturing Process pane, expand the **Features to Review** or **General Mill Finishing** node under the **Machining** node. Right click a GCD and select **Process Setup Options**.



The Process Options editor appears and displays diagnostic information about the selected GCD.

- 2 In the Process Options editor navigation pane, select any GCD in order to display diagnostic information about that GCD.

When you use semi-automated costing (see [Semi-automated Costing](#)), some GCDs are assigned to Features to Review because no other operation was feasible for them under the constraints of semi-automated costing. These constraints include the following:

- Do not assign Contouring to large surfaces. See **Contouring Area Ratio Threshold** in [Machining Node Process Setup Options](#).
- Do not assign General Mill Finishing to any GCD.
- Only assign operations for which a principal or user-defined setup renders the GCDs accessible (see [Setup Axes and Operation Feasibility](#)).

Besides the constraints of semi-automated costing (see above), machining operations are subject to variety of other feasibility constraints, which may be mentioned in diagnostic information. Following are some of the most important requirements on milling operations:

- Geometric tolerance is achievable. See the "Specifying Tolerance and Roughness" section of the *aPriori User Guide*.
- Appropriate setup axis and part-relative tool orientation can be found. See [Setup Axes and Operation Feasibility](#).
- For rounding, the GCD has a constant radius of curvature.

- For side milling, the selected tool has a length-to-diameter ratio that is smaller than the maximum side milling threshold. See **Maximum Side Milling Length to Diameter Ratio** in **Machining Node Process Setup Options**.
- GCD has no sharp corners (corners that would require a 0 tool diameter). Consider whether you should activate a setup axis to allow facing, or (if sharp corners are not the intended geometry) either modify the CAD model or disable feasibility checks for this GCD's operation.
- GCD's extracted dimensions are not unreasonably small.

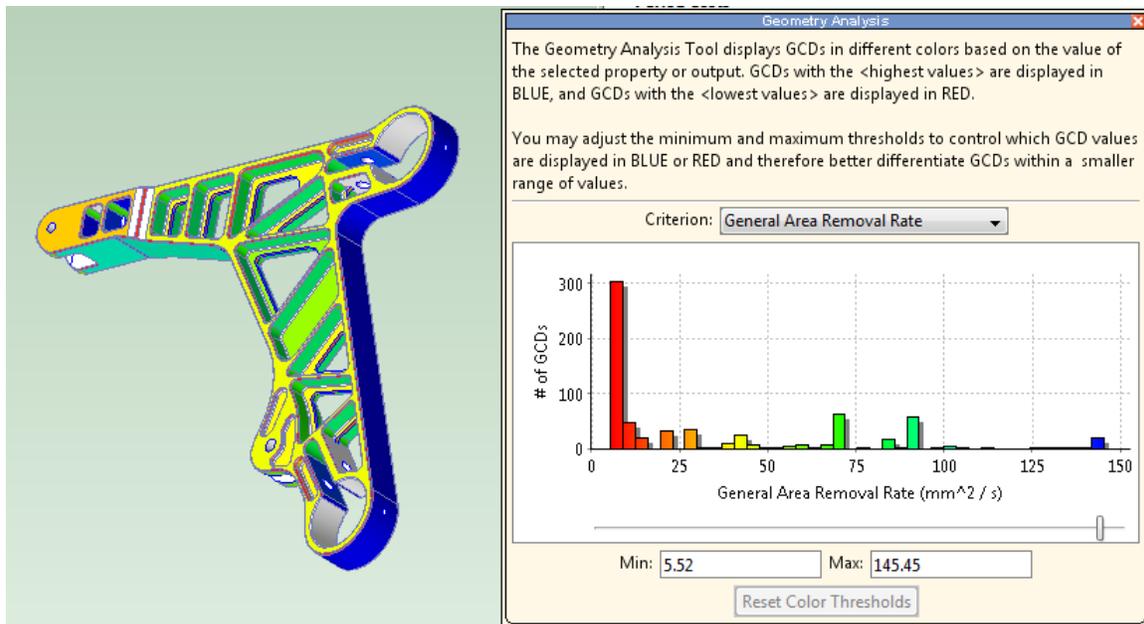
Drilling operations also have constraints on the selected tool's length-to-diameter ratio.

For each GCD assigned to Features to Review, you should consider either explicitly assigning an operation or taking steps to allow aPriori to assign an operation to the GCD during a subsequent costing. See **Modifying Machining Operation Assignments**.

Working with the Heat Map (Geometry Analysis)

You can direct aPriori to display your part in the Component Viewer in the form of a heat map. Each of the part's GCDs is filled in with a color that indicates the value range, for the GCD, of a specified metric.

To enable the heat map, click the Geometry Analysis tool, , in the Component Viewer tool bar. Your part is displayed as a heat map, and the Geometry Analysis bar graph appears.



The bar graph includes a dropdown menu, labelled **Criterion**, which lists the heat map metrics. If you select, for example, the metric General Area Removal Rate, each GCD in the heat map is filled in with a color that indicates the rate of removal for finishing operations assigned to that GCD. If more than one finishing operation is assigned to the GCD, the color indicates the average rate across operations. Warmer colors (like orange and red) indicate higher values; cooler colors (like green and blue) indicate lower values.

Note: The Design to Cost tool for presents the same types of machinability issues as the Heat Map, but in a format that is more user-friendly for casual users who are not experts in machining. See the aPriori User Guide for more information.

Following are some of the heat map metrics (see the aPriori User Guide for a complete list of metrics, as well as information on configuring the Heat Map):

- **General Area Removal Rate:** rate at which the finishing operation for the indicated GCD removes material from the GCD's surface, in unit area per unit time. Removal rate depends on feed, speed, tool diameter, and contact width. Cycle time increases as removal rate decreases—see [Operation Cycle Time and Cut Time Calculations](#).

If the heat map indicates that removal rate for a GCD or group of GCDs is lower than you think it should be, consider making one or more of the following adjustments:

- Increase feed for the GCD(s). See **Requested Feed per Tooth** in [Surface Finishing Milling Options](#).
 - Increase speed for the GCD(s). See **Requested Tool Cutting Speed** in [Surface Finishing Milling Options](#).
 - Modify the tool diameter. A larger tool diameter can increase removal rate, but it can also decrease corner accessibility, rendering certain operations infeasible. A smaller tool diameter can sometimes make a more efficient operation feasible. See **Requested Tool Diameter** in [Surface Finishing Milling Options](#).
 - Modify operation assignment, either by directly assigning an operation to the GCD(s), or else by modifying setups or thresholds. See [Modifying Machining Operation Assignments](#).
- **General Volume Removal Rate:** rate at which the hole-making operation for the indicated GCD removes material from the part, in unit volume per unit time. Removal rate depends on feed and speed. Cycle time increases as removal rate decreases. If the heat map indicates that removal rate for a GCD or group of GCDs is lower than you think it should be, consider increasing feed or speed. See **Requested Feed per Tooth** and **Requested Tool Cutting Speed** in [Surface Finishing Milling Options](#).
 - **Contouring Removal Rate:** rate at which the contouring operation for the indicated GCD removes material from the GCD's surface, in unit area per unit time. Removal rate depends on feed, speed, tool diameter, and contact width. Cycle time increases as removal rate decreases—see [Operation Cycle Time and Cut Time Calculations](#).

If the heat map indicates that removal rate for a GCD or group of GCDs is lower than you think it should be, consider making one or more of the following adjustments:

- Increase feed for the GCD(s). See **Requested Feed per Tooth** in [Surface Finishing Milling Options](#).
- Increase speed for the GCD(s). See **Requested Tool Cutting Speed** in [Surface Finishing Milling Options](#).
- Modify the tool diameter. A larger tool diameter can increase removal rate, but it can also decrease corner accessibility, rendering certain operations infeasible. A smaller tool diameter can sometimes make a more efficient

operation feasible. See **Requested Tool Diameter** in [Surface Finishing Milling Options](#).

- Modify operation assignment, either by directly assigning an operation to the GCD(s), or else by modifying setups or thresholds. See [Modifying Machining Operation Assignments](#).
- **Side Mill Area Removal Rate:** rate at which the side milling operation for the indicated GCD removes material from the GCD's surface, in unit area per unit time. Removal rate depends on feed, speed, tool diameter, and contact width. Cycle time increases as removal rate decreases—see [Operation Cycle Time and Cut Time Calculations](#).

If the heat map indicates that removal rate for a GCD or group of GCDs is lower than you think it should be, consider making one or more of the following adjustments:

- Increase feed for the GCD(s). See **Requested Feed per Tooth** in [Surface Finishing Milling Options](#).
- Increase speed for the GCD(s). See **Requested Tool Cutting Speed** in [Surface Finishing Milling Options](#).
- Modify the tool diameter. A larger tool diameter can increase removal rate, but it can also decrease corner accessibility, rendering certain operations infeasible. A smaller tool diameter can sometimes make a more efficient operation feasible. See **Requested Tool Diameter** in [Surface Finishing Milling Options](#).
- Modify operation assignment, either by directly assigning an operation to the GCD(s), or else by modifying setups or thresholds. See [Modifying Machining Operation Assignments](#).
- **Side Mill Length to Diameter Ratio:** Tool length divided tool diameter. This ratio affects side-milling feasibility. See [Working with Features to Review](#).

If side milling would be appropriate, but the heat map indicates that this value is too small for side milling, check the PSO information entries to see if this caused side milling to be infeasible. If so, you can assign side milling either explicitly or by changing thresholds or setup axes. See **Easy Side Milling Length to Diameter Ratio** and Maximum **Side Milling Length to Diameter Ratio** in [Machining Node Process Setup Options](#).

- **Facing Area Removal Rate:** rate at which the facing operation for the indicated GCD removes material from the GCD's surface, in unit area per unit time. Removal rate depends on feed, speed, tool diameter, tool path, and contact width. Cycle time increases as removal rate decreases—see [Operation Cycle Time and Cut Time Calculations](#).

If the heat map indicates that removal rate for a GCD or group of GCDs is lower than you think it should be, consider making one or more of the following adjustments:

- Increase feed for the GCD(s). See **Requested Feed per Tooth** in [Surface Finishing Milling Options](#).
- Increase speed for the GCD(s). See **Requested Tool Cutting Speed** in [Surface Finishing Milling Options](#).
- Modify the tool diameter. A larger tool diameter can increase removal rate, but it can also decrease corner accessibility, rendering certain operations

- infeasible. A smaller tool diameter can sometimes make a more efficient operation feasible. See **Requested Tool Diameter** in [Surface Finishing Milling Options](#).
- Modify operation assignment, either by directly assigning an operation to the GCD(s), or else by modifying setups or thresholds. See [Modifying Machining Operation Assignments](#).
 - **Time Tool Machines Air**: percentage of engagement time that is non-chipmaking time, that is, percentage of time during which the tool is engaged (spinning) that the tool is not in contact with the GCD surface (see [Operation Cycle Time and Cut Time Calculations](#)). If the heat map indicates that this metric is too high, consider reducing tool diameter—see **Requested Tool Diameter** in [Surface Finishing Milling Options](#).
 - **Cutting Speed Reduction Factor**: percentage by which the recommended speed is reduced due to limitations of the current machine. aPriori reduces the speed used for calculating removal rate, when aPriori's recommended speed exceeds the machine's speed capabilities. If the heat map indicates that the reduction factor is high, consider explicitly selecting a machine that supports higher speeds.
 - **Cycle Time**: time to perform the assigned operation on the indicated GCD. If the heat map indicates that the cycle time is high, examine other metrics for the indicated GCD, such as removal rate and tool diameter, or consider modifying operation assignment.
 - **Surface Finishing Tool Diameter**: diameter of the tool selected for the assigned operation on the indicated GCD. If the heat map indicates that this value is too small for a GCD or group of GCDs, consider increasing tool diameter, either directly with a process setup option (See **Requested Tool Diameter** in [Machining Node Process Setup Options](#)) or indirectly by activating a setup that provides a better angle on the GCDs corners.
 - The heat map also contains an item, Features to Review, which applies to features that have been assigned to Features to Review or General Mill Finishing. See [Working with Features to Review](#).

Modifying Machining Operation Assignments

If your part has a GCD that has no operation assigned to it, or has the wrong operation assigned to it, you can modify operation assignment in any of the following ways:

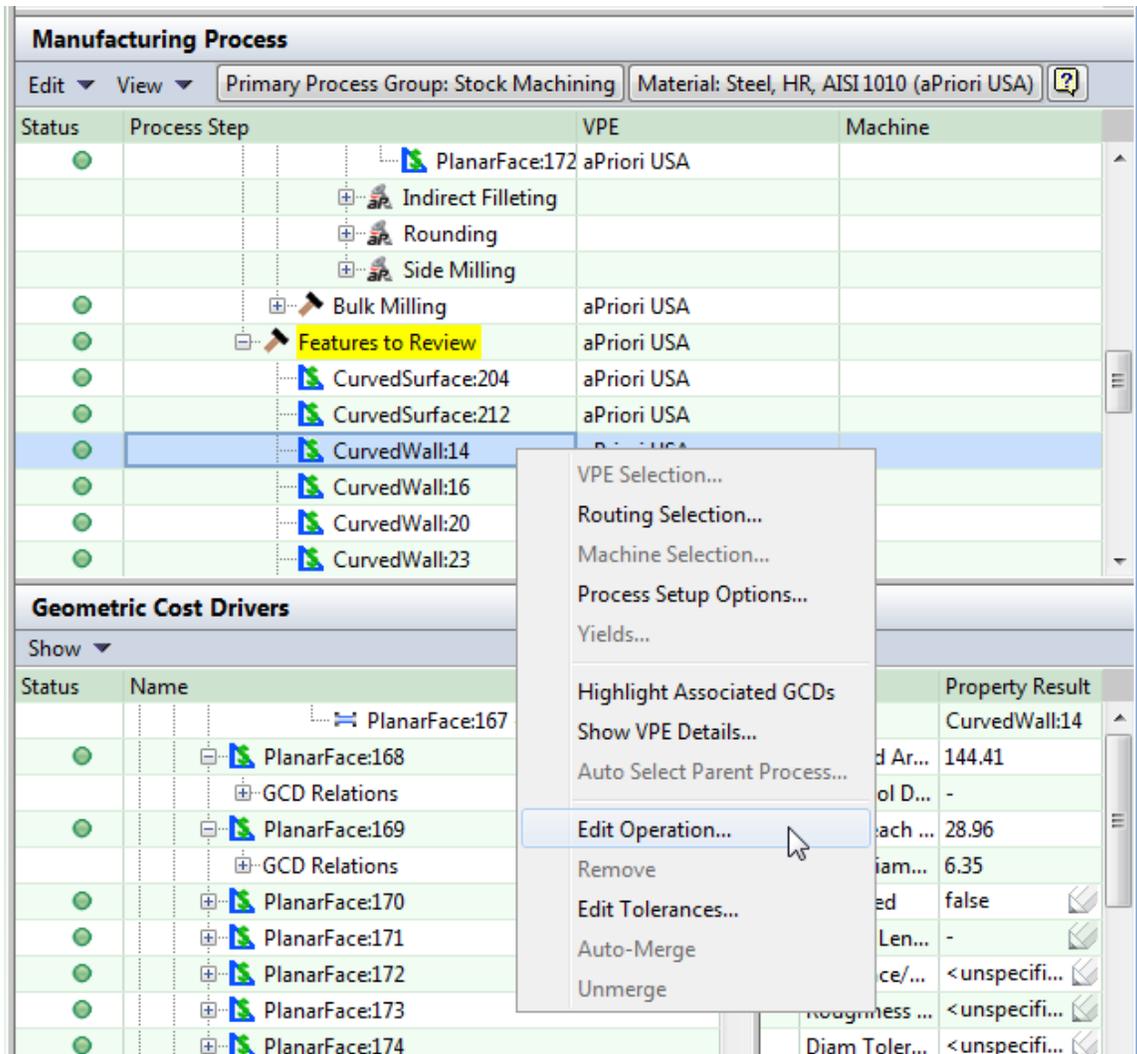
- Manually assign an operation to the GCD. See [Explicitly Assigning Operations to GCDs](#) and [Manually Assigned Operations](#).
- Modify setup axes:
 - Explicitly assign setup axes to the GCD. See [Activating Setup Axes](#).
 - Change which setup axes are designated as principal. See [Overriding Principal Setup Axes](#).
 - Activate new non-principal setup axes. See [Activating Setup Axes](#).

- Use process setup options to change thresholds. See **Contouring Area Ratio Threshold**, **Easy Side Milling Length to Diameter Ratio**, and **Maximum Side Milling Length to Diameter Ratio** in **Machining Node Process Setup Options**.

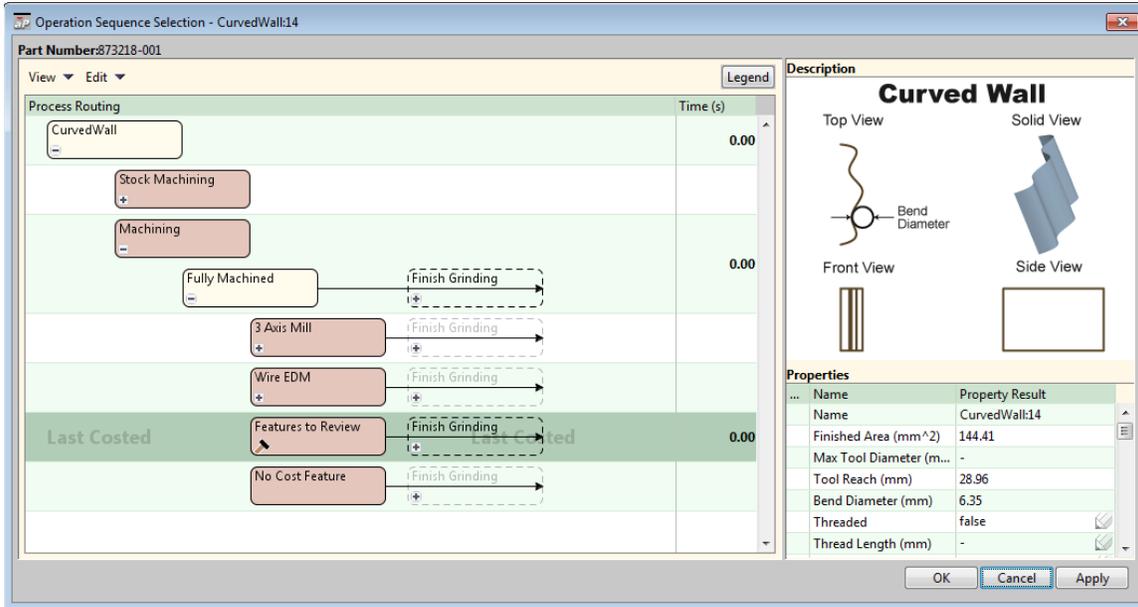
Explicitly Assigning Operations to GCDs

To explicitly assign an operation to a GCD, Follow these steps:

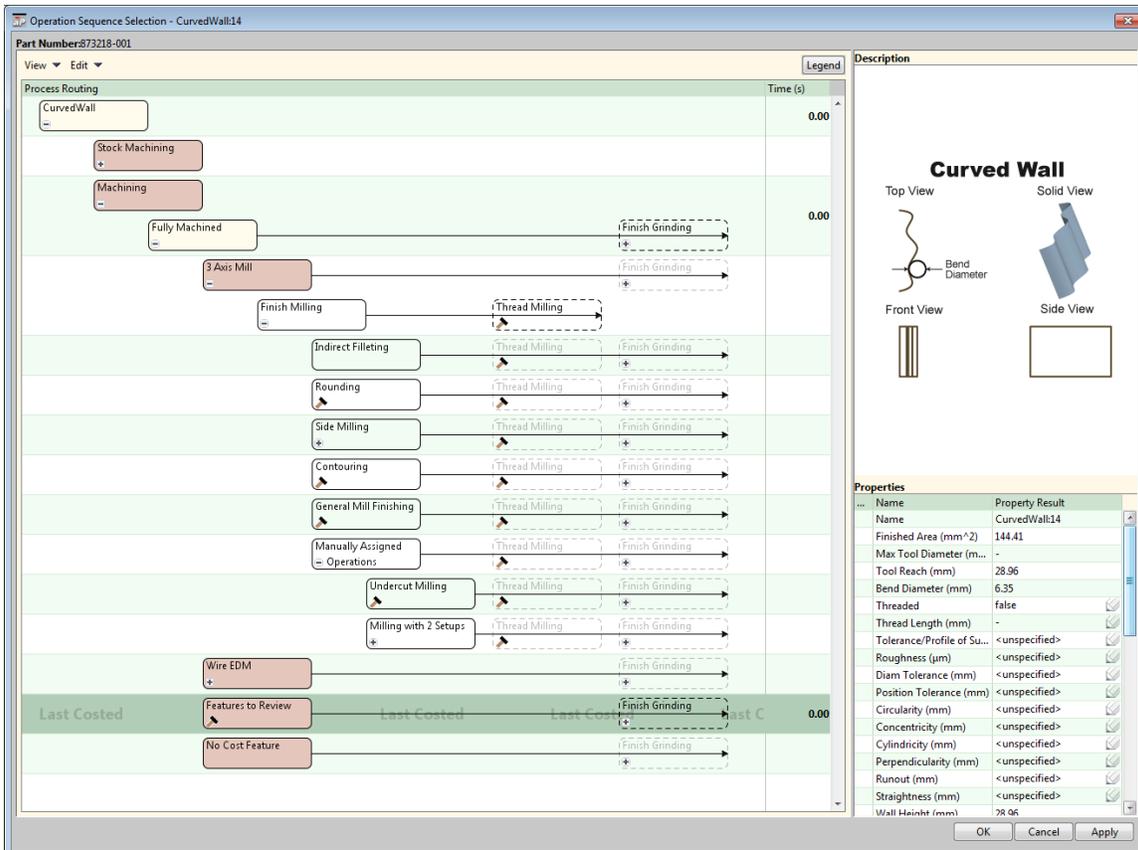
- Right click the GCD in the Manufacturing Process pane (e.g., under Features to Review or General Mill Finishing) or in the Viewer, and select **Edit Operation....**



The Operation Sequence Selection editor appears.



- Expand nodes of the routing diagram if necessary, and click the operation you want to assign to the GCD. In some cases you may want to disable feasibility checks (right-click the operation and select **Rule/Status**; uncheck the **Operation** checkbox).



Manually Assigned Operations

The following operations are never auto-assigned, but are useful in many cases for which the auto-assigned operations are infeasible:

- Undercut Milling
- Chamfer Milling
- Mill Grooving
- No Cost Feature

Undercut Milling

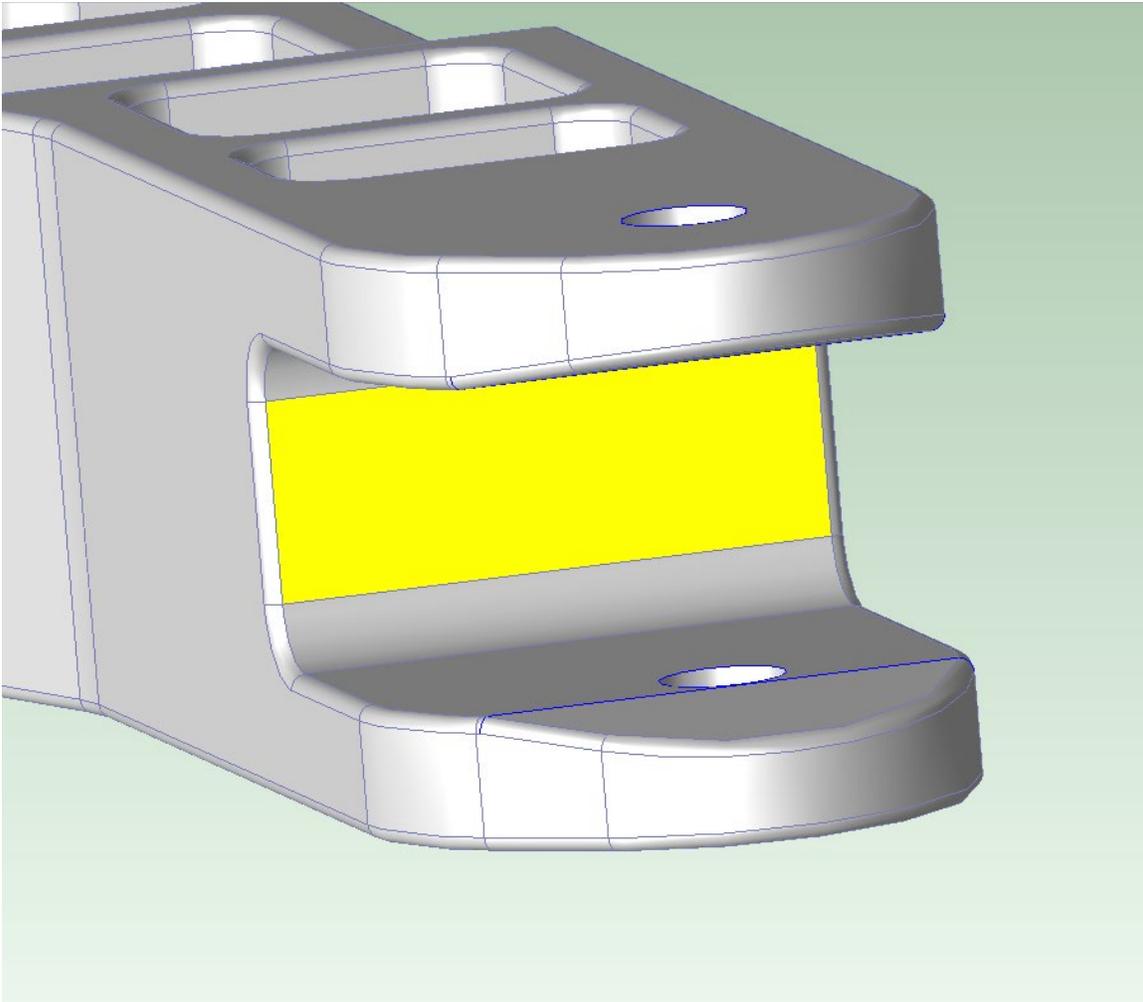
Undercut walls can be made by T-slot cutters with the Undercut Milling operation.

You can assign Undercut Milling to two types of GCDs:

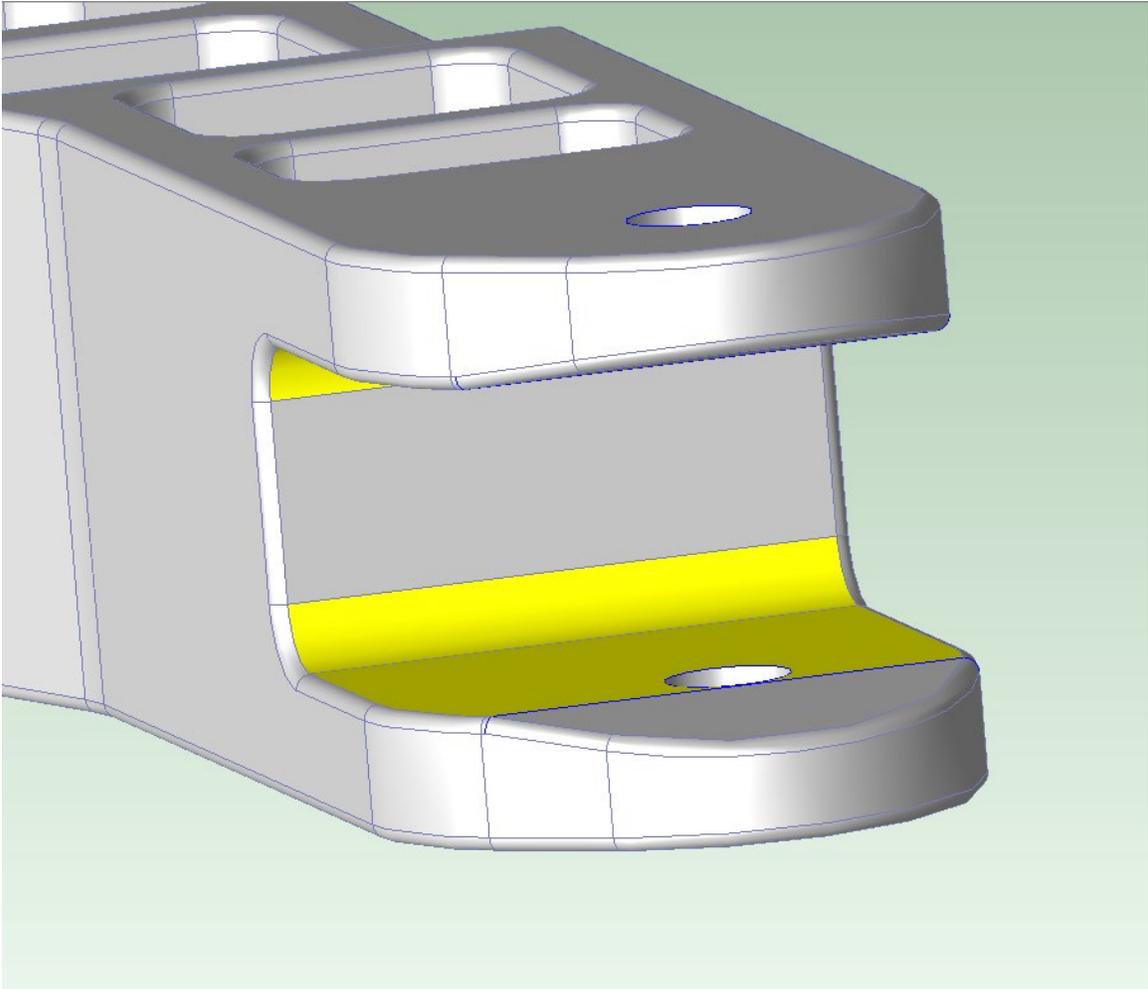
- Planar faces
- Curved walls

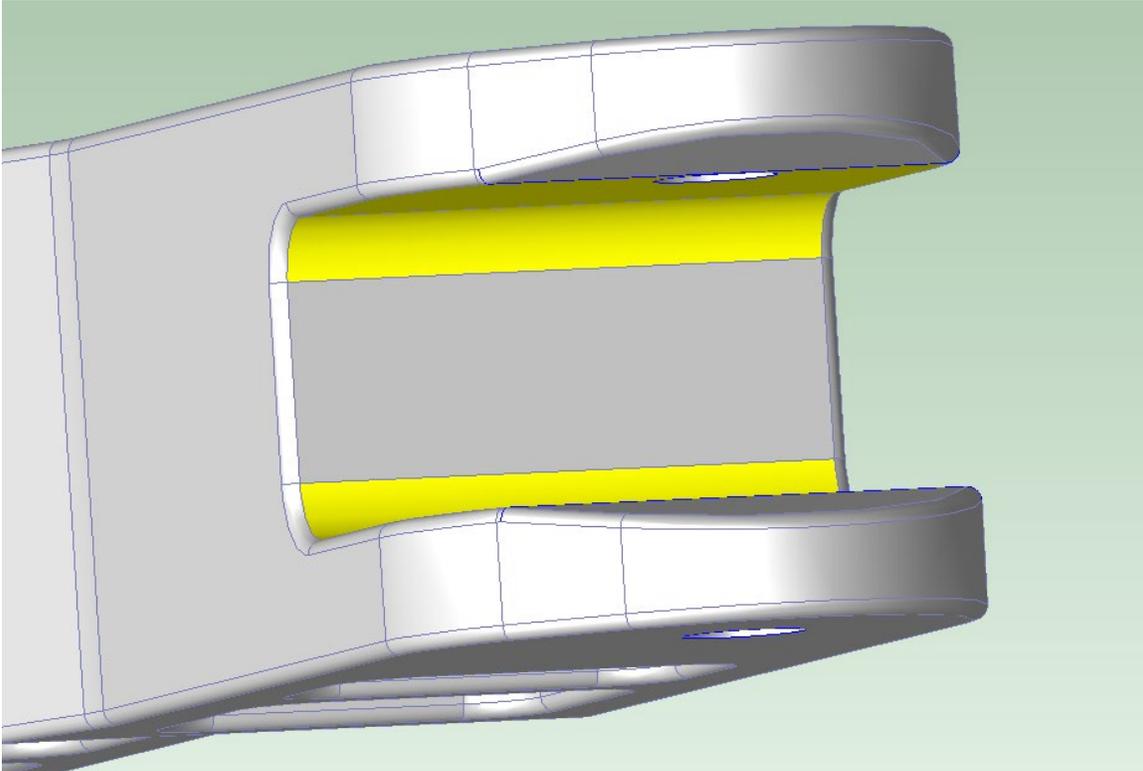
When you assign undercut milling to a GCD, adjacent GCDs might be handled by the same operation; be sure to assign the operation **No Cost Feature** to such adjacent GCDs.

The following illustration shows a planar face (in yellow) to which it is appropriate to assign Undercut Milling:

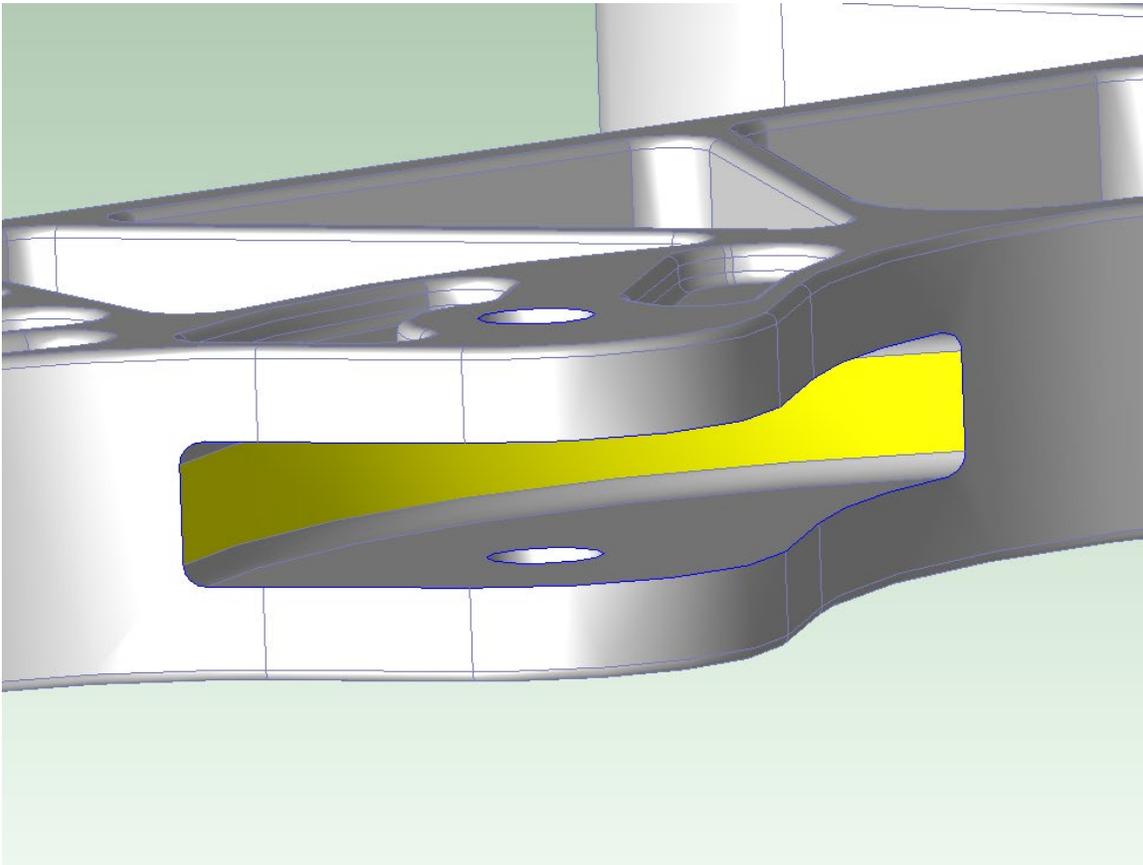


Given the assignment of Undercut Milling to the planar face as shown above, the following illustrations show the surfaces (in yellow) to which it is appropriate to assign No Cost Feature, since these surfaces will also be created by the Undercut Milling operation:

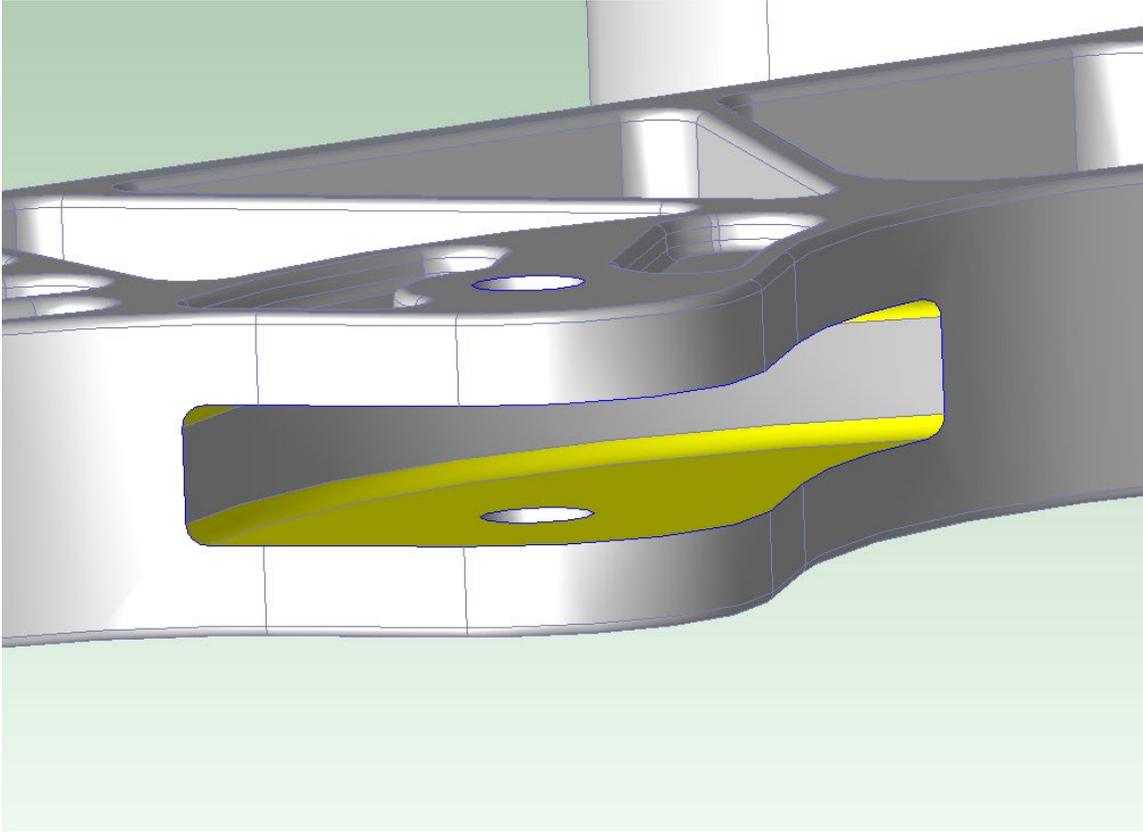


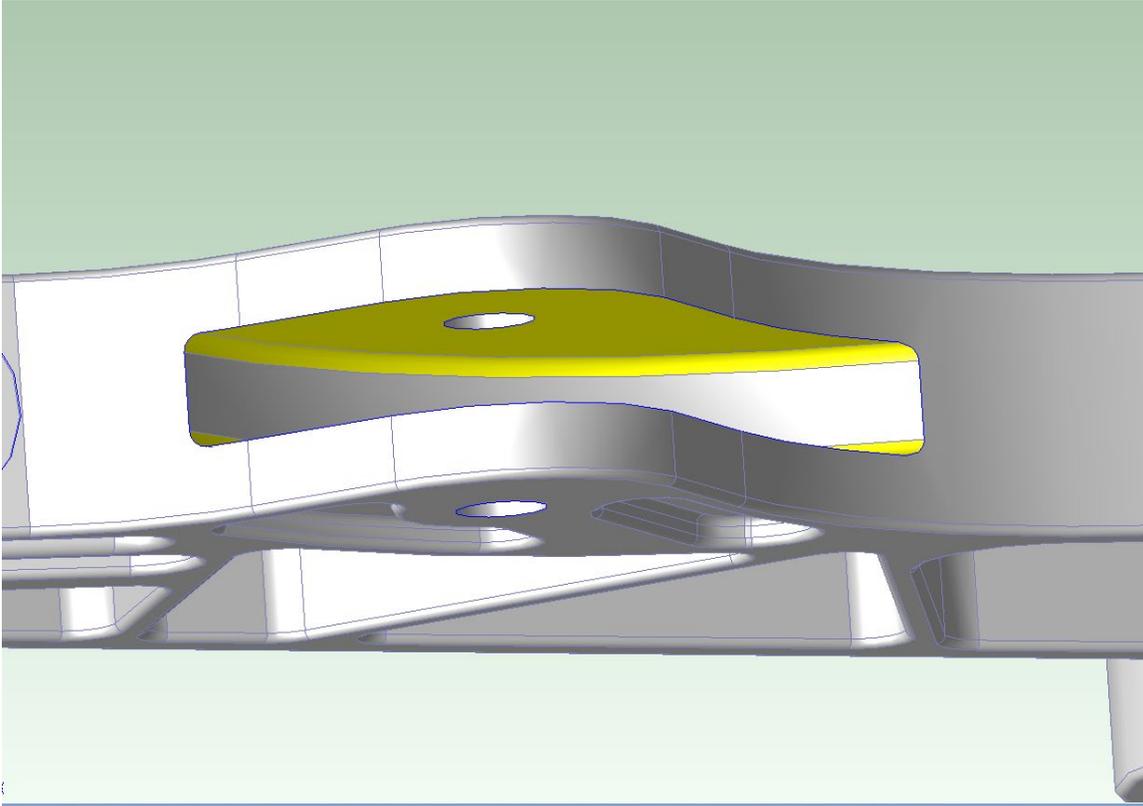


The following illustration shows a curved wall (in yellow) to which it is appropriate to assign Undercut Milling:

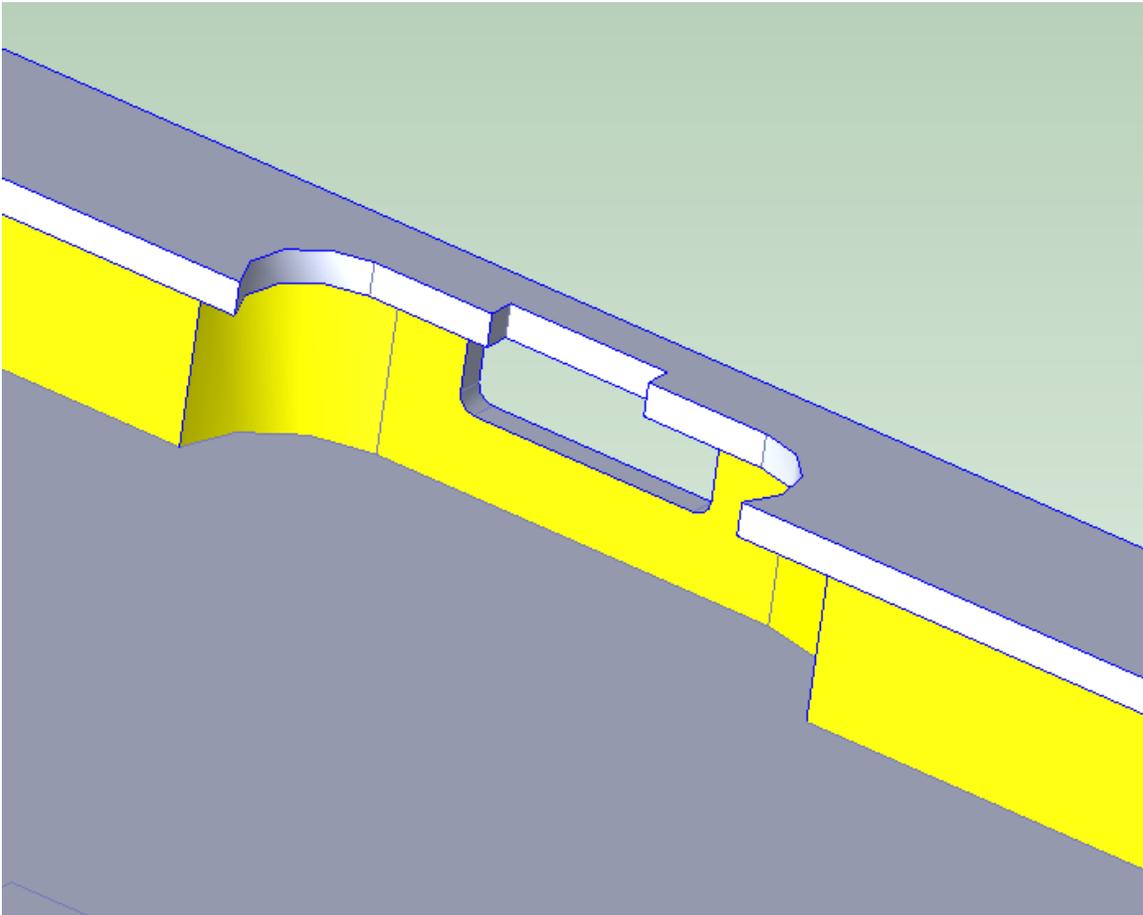


Given the assignment of Undercut Milling to the curved wall as shown above, the following illustrations show the surfaces (in yellow) to which it is appropriate to assign No Cost Feature, since these surfaces will also be created by the Undercut Milling operation:



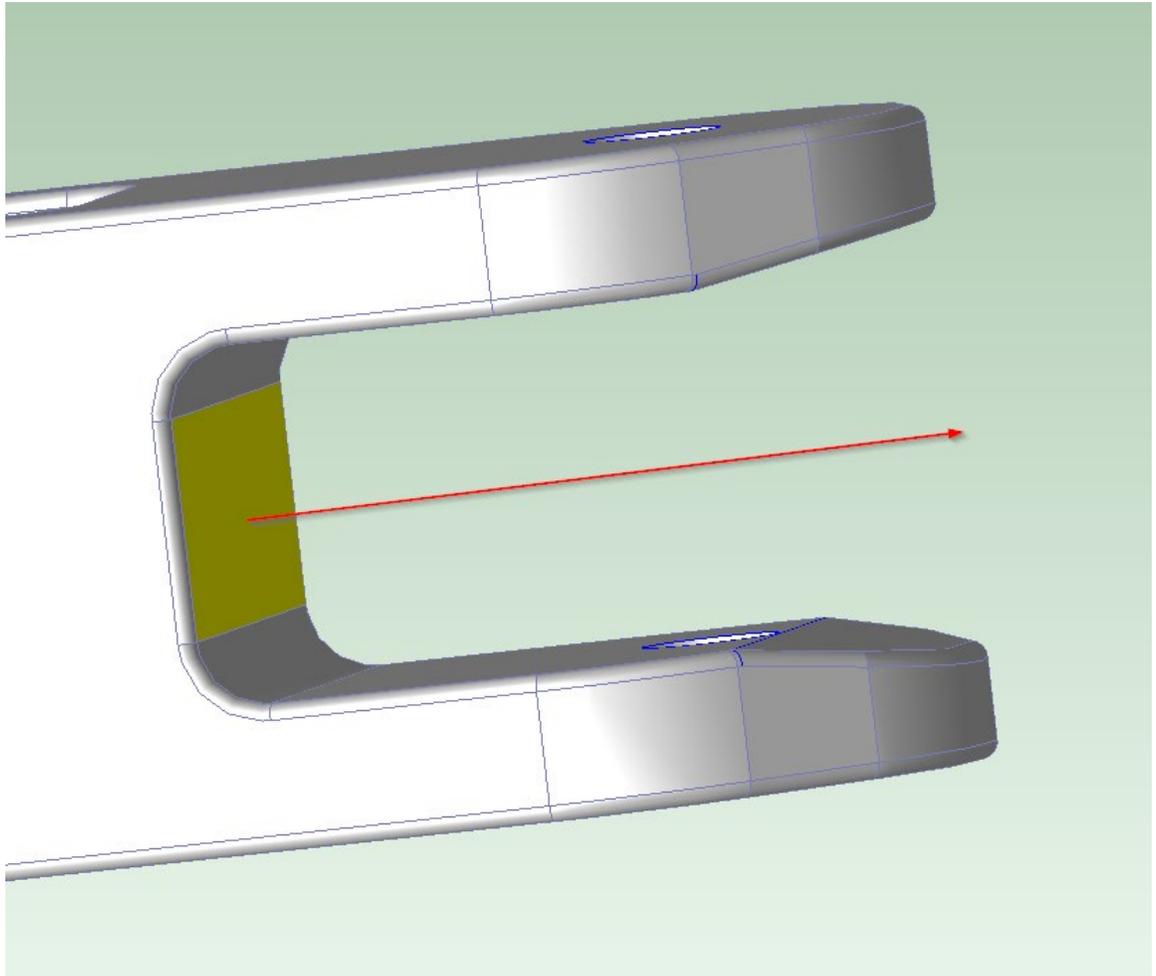


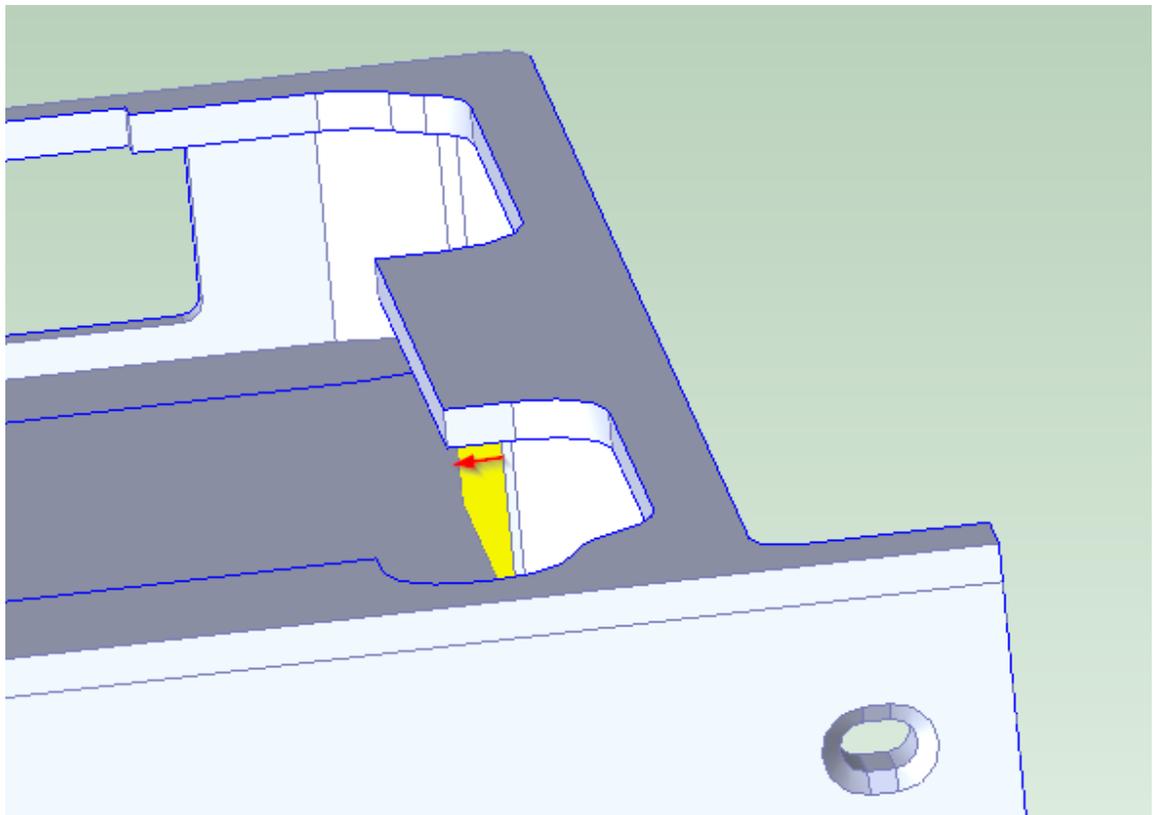
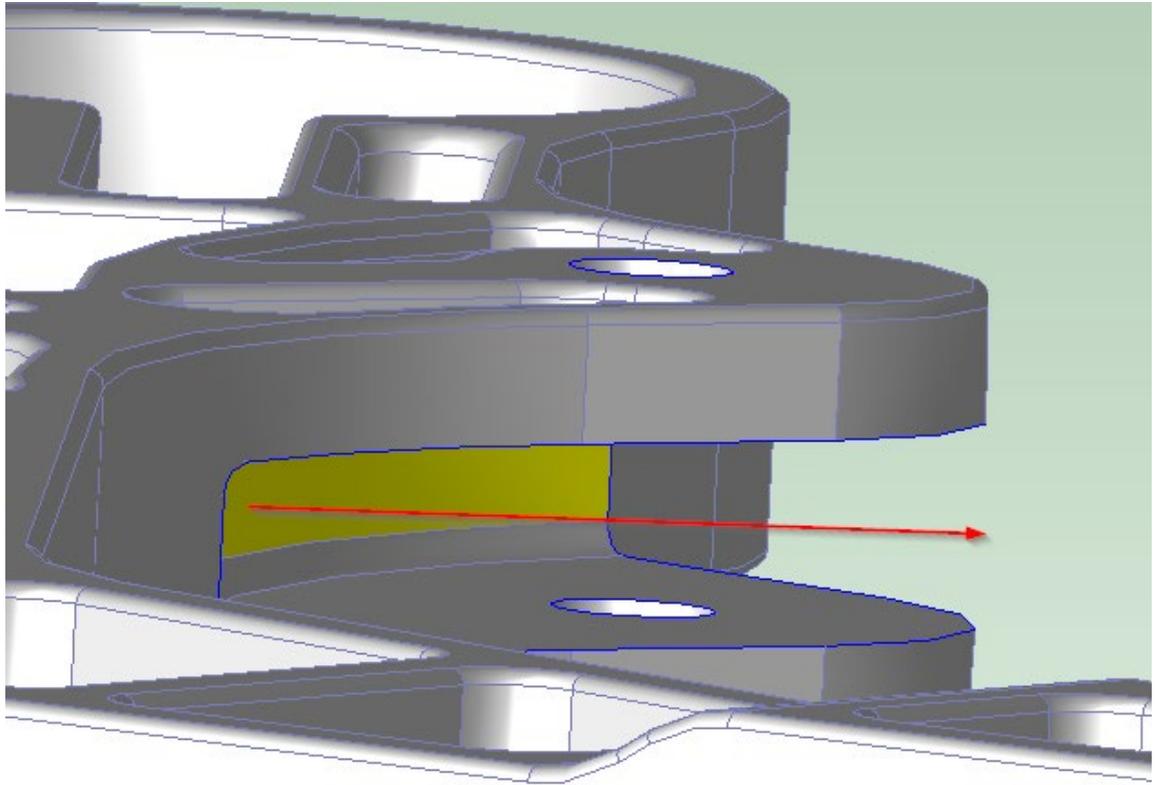
Sometimes use of Undercut Milling renders feasible other operations on adjacent, partially obstructed surfaces, because the obstructed section is indirectly machined by the Undercut Milling tool. Consider, for example, the following illustration, which shows planar faces and curved walls (in yellow) to which it is appropriate to assign Undercut Milling:



The lip around the part's interior partially obscures the interior floor of the part (which makes auto-assigned facing infeasible). But the obstructed section of the floor is indirectly machined by Undercut Milling, and the remaining portion of the floor is accessible to facing. So in this case, the interior floor of the part should be manually assigned Face Milling, with feasibility checks disabled. No Cost Feature operations should be manually assigned to the underside of the lip.

When you use Undercut Milling, you *must* supply a value for the process setup option **Maximum Undercut Depth** (right-click Undercut Milling node in the Operation Sequence Selection editor, and select **Process Setup Options...**). Enter a value in millimeters with up to 2 decimal places. This value is the largest distance from a point on the selected surface, along the normal to the surface at that point, to the end of the undercut. The arrows in the figures below show the undercut depth:





Tool diameter is set to two and half times the maximum undercut depth, by default. You can override this default with the operation-level setup option **Requested Tool Diameter**.

Cycle time for this operation depends in part on the following:

- Length along which the tool must travel, including the approach and depart distances: the length of the groove is determined by geometry extraction. The approach and depart distances are each equal to the tool radius, by default. You can override the default and explicitly specify the approach/depart distance with the operation-level process setup option **Approach Depart Distance**. This can be set to 0 for surfaces within a surface chain that should be continuously milled.
- Number of passes: by default, one pass is assumed, but you can specify the number of passes with the operation-level setup option **Number of Finishing Passes**.
- Tool feed: by default, this is based on the data in **tblGrooveMilling**. You can override the default, and specify feed with the operation-level setup options **Requested Feed Per Tooth** and **Requested Number of Teeth**. See [Surface Finishing Milling Options](#) for more information.
- Tool speed: by default, this is based on the data in **tblGrooveMilling**. You can override the default, and specify speed with the operation-level setup option **Requested Tool Cutting Speed**. See [Surface Finishing Milling Options](#) for more information.

You can override the calculated cycle time with the operation-level setup option **Requested Cycle Time**.

This operation is available for the following processes:

- 3 Axis Mill
- 4 Axis Mill
- 5 Axis Mill

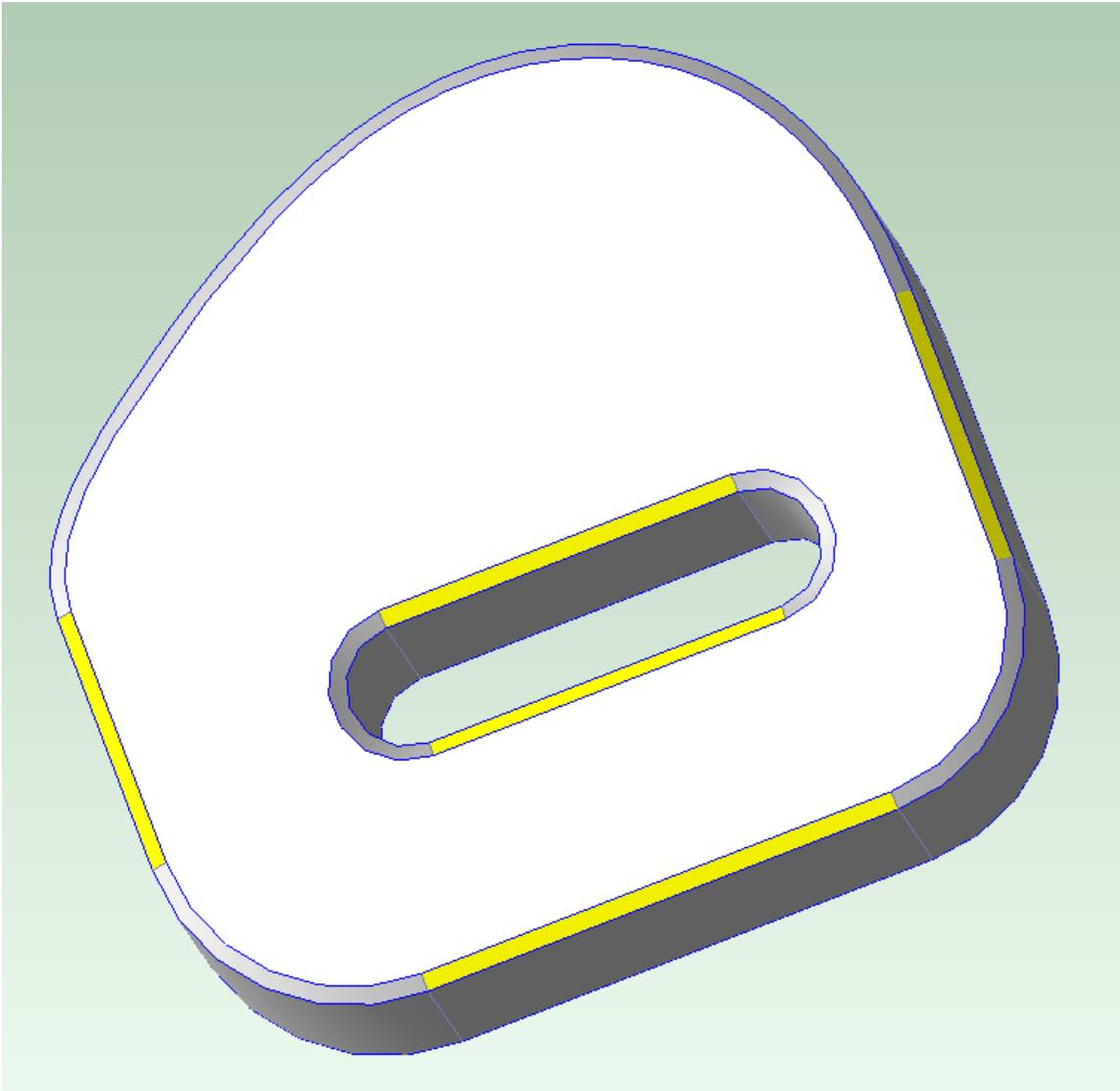
Chamfer Milling

Chamfer milling: narrow, angled planes can be made with a chamfering end mill. Use this operation for GCDs that are not recognized by aPriori as chamfered edges.

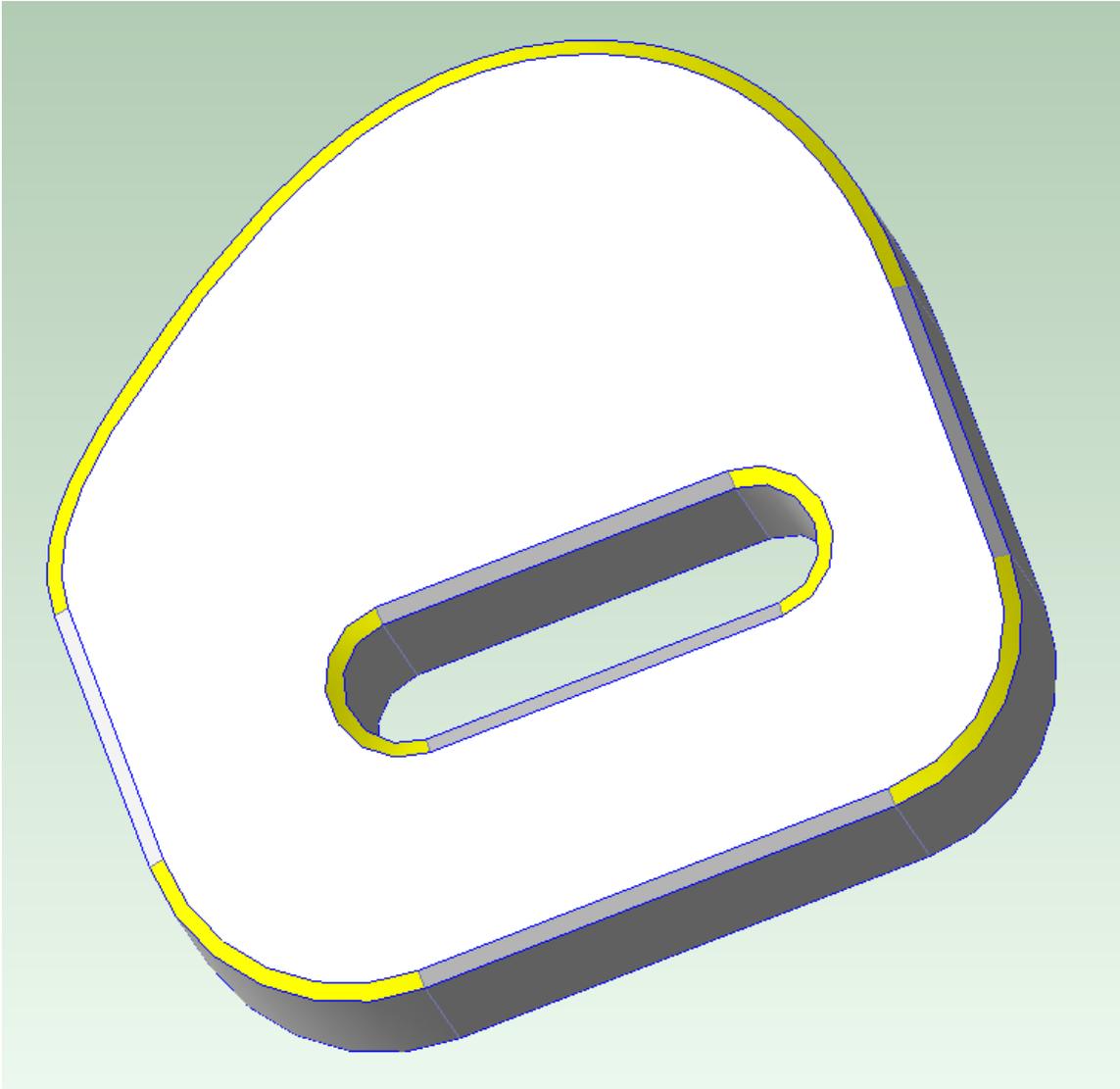
You can assign Chamfer Milling to two types of GCDs:

- Planar faces
- Ruled, curved surfaces. A ruled, curved surface is a Curved Surface GCD whose **isRuled** property (as listed in the Geometric Cost Drivers pane) is **true**. A ruled, curved surface can be thought of as generated by the motion of a line segment, or rule, translated and rotated through space

The following illustration shows planar faces (in yellow) for which Chamfer Milling is appropriate:



The following illustration shows ruled, curved surfaces (in yellow) for which Chamfer Milling is appropriate:



Cycle time for Chamfer Milling depends in part on the following:

- Length of GCD: for planar faces, this is determined by geometry extraction, by default. For ruled, curved surfaces, it is estimated based on the extracted geometry, by default. You can override the default and explicitly specify the length with the operation-level process setup option **Requested Length To Chamfer**.
- Number of passes: by default, one pass is assumed, but you can specify the number of passes with the operation-level setup option **Number of Finishing Passes**.
- Linear speed of the tool along the edge to chamfer: by default, this is based on the data in **tblChamfering**. You can override the default, and specify the linear speed with the operation-level setup option **Requested Tool Linear Speed**.

You can override the calculated cycle time with the operation-level setup option **Requested Cycle Time**.

This operation is available for the following processes:

- 3 Axis Lathe
- 3 Axis Bar Fed Lathe

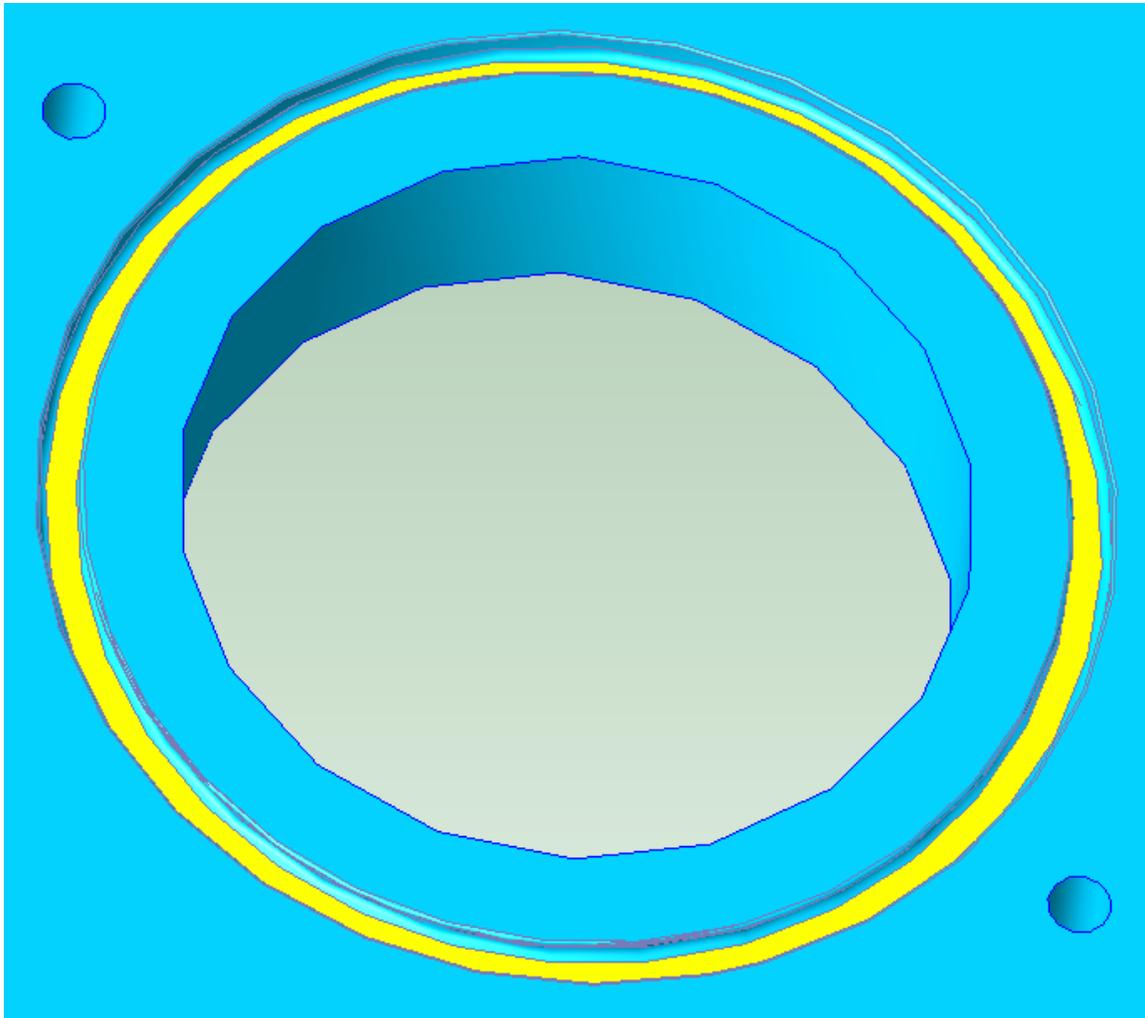
- 3 Axis Mill
- 4 Axis Mill
- 5 Axis Mill
- Mill Turn

Mill Grooving

Mill grooving: O-ring grooves can be made with a keyseat mill. Use this operation for combinations of curved walls, curved surfaces, and planar faces that are not recognized by aPriori as a ring.

Assign Mill Grooving to a planar face, and consider assigning No Cost Feature to some or all of the surrounding surfaces.

The following illustration shows a planar face (in yellow) to which it is appropriate to assign Mill Grooving:



The tool is assumed to be a custom fit for the slot. Tool height is determined by the width of the slot. Tool diameter is determined by the depth of the slot, by default; you can override the default tool diameter with the operation-level setup option **Requested Tool Diameter**.

Cycle time depends in part on the following:

- Length along which the tool must travel: this is estimated as half the GCD's perimeter. You can override the default and explicitly specify the length with the operation-level process setup option **Requested Groove Length**.
- Number of passes: by default, three passes are assumed, but you can specify the number of passes with the operation-level setup option **Number of Finishing Passes**.
- Tool feed: by default, this is based on the data in **tblGrooveMilling**. You can override the default, and specify feed with the operation-level setup options **Requested Feed Per Tooth** and **Requested Number of Teeth**. See [Surface Finishing Milling Options](#) for more information.
- Tool speed: by default, this is based on the data in **tblGrooveMilling**. You can override the default, and specify speed with the operation-level setup option **Requested Tool Cutting Speed**. See [Surface Finishing Milling Options](#) for more information.

You can override the calculated cycle time with the operation-level setup option **Requested Cycle Time**.

This operation is available for the following processes:

- 3 Axis Mill
- 4 Axis Mill
- 5 Axis Mill
- Mill Turn

No Cost Feature

No Cost Feature: if an operation indirectly machines adjacent GCDs along with the GCD that the operation is assigned to, assign No Cost Feature to those adjacent GCDs, to prevent double-costing. See, for example, [Undercut Milling](#), above.

Working with Gears, Splines, Sprockets, and Flutes

aPriori can cost parts that include gears, as well as parts that include flutes, splines, or sprockets. Geometry extraction recognizes these in your CAD model as *AxiGroove* GCDs. If your part includes gears, flutes, splines, or sprockets that are not represented in your CAD model, you can explicitly add them as *AxiGroove* GCDs by using the Component Viewer and the **Gear Definition** dialog. In addition, if your part includes gears, flutes, splines, or sprockets that are roughly or incompletely represented in your CAD model, you can use the **Gear Definition** dialog to edit and supplement the extracted *AxiGroove* properties.

Supported *AxiGroove* types include the following:

- Internal and external spur gears
- Internal and external helical gears
- Straight and spiral bevel gears

- Internal and external splines
- Sprockets
- Flutes

Note that while Flutes are extracted as AxiGroove GCDs, they are routed, by default, to milling processes that are not specific to gear making (specialized gear-making cutting mills and tool paths are *not* used in this case).

aPriori does not currently support the following:

- Face gears
- Worm and screw gears
- Racks
- Hypoid gears
- Incomplete patterns of teeth, sector or partial gears, gears that skip teeth, and gears that have variations among the teeth—only GCDs that are fully symmetric with respect to an axis are supported.
- Gears whose valleys have protrusions

See [Controlling What Gets Recognized as an AxiGroove](#) for more information. See also [Gear Type](#).

Gear recognition and costing is supported for the following process groups:

- 2-Model Machining
- Bar&Tube
- Casting
- Forging
- Powder Metal
- Stock Machining

Specialized gear-making machines include the following:

- Bevel Gear Cutting Machine
- Broach
- Spline Roller
- Hob Machine
- Shaper
- Shaver

This section contains the following subsections:

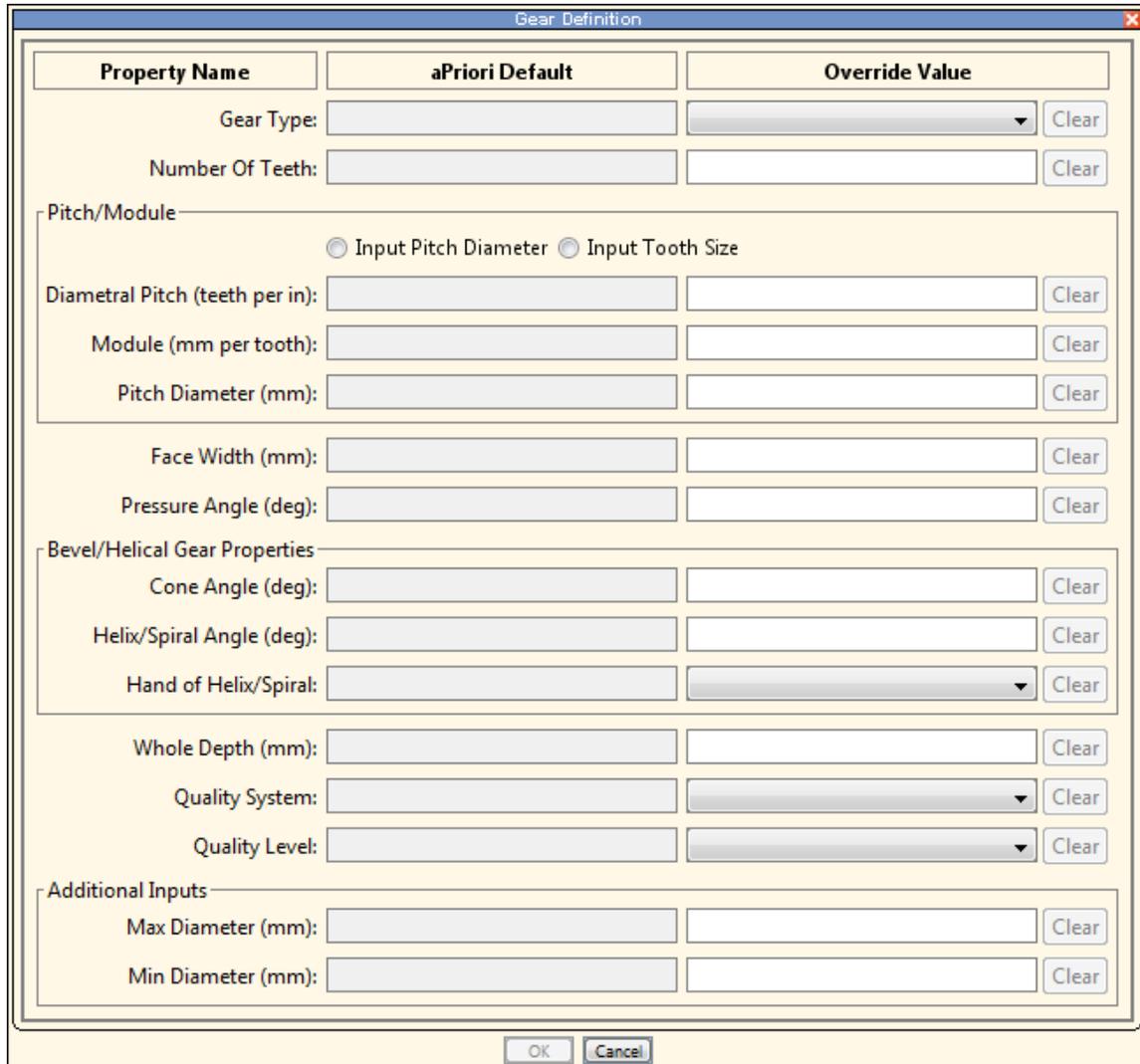
- [Defining AxiGrooves](#)
- [Overriding AxiGroove Properties](#)
- [Using the Gear Definition Dialog](#)
- [AxiGroove Geometric Properties](#)
- [Process and Operation Routing and Feasibility for Gears](#)

- Site Variables for Gears
- Cost Model Variables for Gears
- Setup Options for Gears

Defining AxiGrooves

Follow these steps to define an AxiGroove that is not represented in your CAD model:

- 1 Ensure that your part is displayed in the Component Viewer. In the Component Viewer tool bar, click the gear tool, . The **Gear Definition** dialog appears.



Property Name	aPriori Default	Override Value
Gear Type:		<input type="text"/> Clear
Number Of Teeth:		<input type="text"/> Clear
Pitch/Module		
<input type="radio"/> Input Pitch Diameter <input type="radio"/> Input Tooth Size		
Diametral Pitch (teeth per in):		<input type="text"/> Clear
Module (mm per tooth):		<input type="text"/> Clear
Pitch Diameter (mm):		<input type="text"/> Clear
Face Width (mm):		<input type="text"/> Clear
Pressure Angle (deg):		<input type="text"/> Clear
Bevel/Helical Gear Properties		
Cone Angle (deg):		<input type="text"/> Clear
Helix/Spiral Angle (deg):		<input type="text"/> Clear
Hand of Helix/Spiral:		<input type="text"/> Clear
Whole Depth (mm):		<input type="text"/> Clear
Quality System:		<input type="text"/> Clear
Quality Level:		<input type="text"/> Clear
Additional Inputs		
Max Diameter (mm):		<input type="text"/> Clear
Min Diameter (mm):		<input type="text"/> Clear

- 2 In the Component Viewer, click an appropriate surface to indicate the location of the gear to be defined. This defines an AxiGroove that is bounded by the specified surface. You can adjust the exact geometric properties of the gear in the next step.



An appropriate surface is both about a turning axis and one of the following:

- Cylindrical
- Conical
- Inside of a hole or ring

When you hover over a surface, aPriori highlights it if it is appropriate.

If a surface is intended to be turnable, but modeling errors prevent extraction of an **IS ABOUT** relation with a turning axis, you can add a user-defined turning axis. Click the Setup Axis icon in the Viewer toolbar, and select **Modify Turning Axes....** Re-extract GCDs once you have created the new turning axis.

When you click an appropriate surface, aPriori populates the fields of the **Gear Definition** dialog with default values that are based on the properties of the selected surface. It chooses a default gear type (which you can modify in the next step) based on the shape of the surface (for example spur gear for cylindrical surfaces and bevel gear for conical surfaces), as well as on whether the surface is internal or external to the part. When aPriori populates the dialog with default values, it displays only the fields that are relevant to the chosen gear type.

Note that you cannot graphically specify the gear width, but rather must specify it with the **Face Width** field of the dialog.

Property Name	aPriori Default	Override Value
Gear Type:	External Spur	<input type="text"/> Clear
Number Of Teeth:	10	<input type="text"/> Clear
Pitch/Module		
	<input type="radio"/> Input Pitch Diameter <input checked="" type="radio"/> Input Tooth Size	
Module (mm per tooth):	2.89	<input type="text"/> Clear
Face Width (mm):	69.44	<input type="text"/> Clear
Pressure Angle (deg):	14.50	<input type="text"/> Clear
Whole Depth (mm):	5.63	<input type="text"/> Clear
Quality System:	AGMA New Standard	<input type="text"/> Clear
Quality Level:	A8	<input type="text"/> Clear
Additional Inputs		
Max Diameter (mm):	31.75	<input type="text"/> Clear
Min Diameter (mm):	26.12	<input type="text"/> Clear

- For each field of the **Gear Definition** dialog, if you do not want to use the default provided in the left-hand column (labelled **aPriori Default**), enter a value in the right-hand column (labelled **Override Value**). Be sure to enter the correct number of teeth. See [Using the Gear Definition Dialog](#) for information on each field.

Overriding AxiGroove Properties

If aPriori extracts an AxiGroove GCD from your CAD model, you can edit its properties by using the **Gear Definition** dialog. Follow these steps to edit gear properties:

- Select the axiGroove that you want to modify by doing one of the following:
 - Select the desired AxiGroove in the Component Viewer.
 - Select the desired AxiGroove in the **Geometric Cost Drivers** pane, under **Volumes > Axi Grooves**.

- 2 Bring up the **Gear Definition** dialog by doing one of the following:
 - Right click in the Component Viewer, and select **Gear Definition....**
 - Right click the selected AxiGroove in the **Geometric Cost Drivers** pane, and select **Gear Definition....**
 - Double click an editable field in **Geometric Cost Drivers** pane. Editable fields contain the pencil icon .
- 3 For each field of the **Gear Definition** dialog, enter a value in the right-hand column (labelled **Override Value**) if you do not want to use the default provided in the left-hand column (labelled **aPriori Default**). See [Using the Gear Definition Dialog](#) for information on each field.

Using the Gear Definition Dialog

Use the Gear Definition dialog to do either of the following:

- Define an AxiGroove that is not represented in your CAD model. See [Defining AxiGrooves](#).
- Edit the properties of an AxiGroove that aPriori has extracted from your CAD model. See [Overriding AxiGroove Properties](#).

For each field of the **Gear Definition** dialog, enter a value in the right-hand column (labelled **Override Value**), if you do not want to use the default provided in the left-hand column (labelled **aPriori Default**). The dialog includes only those fields that are relevant to the type of gear currently specified in the **Gear Type** field.

Following are the fields that can appear in the dialog (each field is described in detail below):

- Gear Type
- Number of Teeth
- PitchDiameter/Tooth Size Radio Buttons
- Module
- Pitch Diameter
- Face width
- Pressure Angle
- Cone Angle
- Helix Angle
- Hand of Helix
- Spiral Angle
- Hand of Spiral
- Whole Depth
- Quality System
- Quality Level
- Max Diameter

- Min Diameter

Gear Type

aPriori supports several types of AxiGrooves, including these types of gears:

- Internal Spur
- External Spur
- Internal Helical
- External Helical
- Spiral Bevel
- Straight Bevel

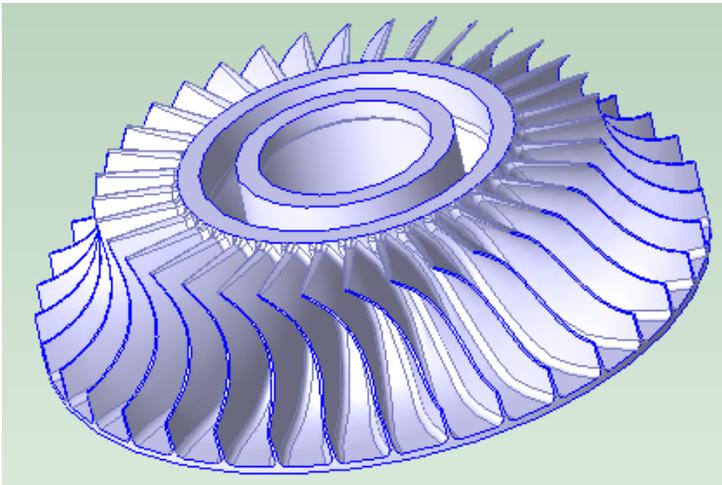
aPriori also supports these types of AxiGrooves, which are not gears:

- Sprocket
- Flutes
- Internal Spline
- External Spline

Some AxiGrooves don't have the geometry characteristic of a gear, flute, spline, or sprocket; these are categorized as being of unknown type:

- <Unknown>

For example, an AxiGroove is classified as unknown if its teeth are obstructed from the radial direction, as with the following pattern of impeller blades and valleys:



In this case, the geometric property **Has Radial Undercut** is **true** for the GCD (as listed in the Geometric Cost Drivers pane):

Geometric Cost Drivers			
Show ▾			
Status	Name	Name	Property Result
●	Component	Approach From	OD
●	Volume	Axial Length	42.18
●	Stock Trims [1]	Max Diameter	181.08
●	Bulk Removals [1]	Min Diameter	91.41
●	Rings [3]	Volume	190,843.36
●	Gear [1]	Valley Axial Extent	0.00
	Gear1	Helix Total Twist Angle	-
●	Holes	Has Radial Undercut	true
●	Surfaces	Tooth To Valley Volume Ratio	0.18
●	Other	Dbg Cad Key Text	1.0:62:1013760,987423:
	GCD Relations	Dbg Min Gcd Version	0.00
		Requested	< auto-select >
		Selected	-
		Time (s)	-
		Status	

By default, axisGrooves classified as **<Unknown>**, as well as those classified as Flutes, are routed to milling processes that are not specific to gear making (specialized gear-making cutting mills and tool paths are *not* used in this case).

Number of Teeth

This is the total number of gear teeth. For user-defined gears, this defaults to a value that is based on surface diameter. Be sure to enter the correct number of teeth.

PitchDiameter/Tooth Size Radio Buttons

For user-defined gears, do one of the following:

- Select the **Input Pitch Diameter** radio button to display the **Pitch Diameter** field. See [Pitch Diameter](#).
- Select the **Input Tooth Size** radio button to display the **Module** field. See [Module](#).

Module

Displayed only if the **Input Tooth Size** radio button is selected. See [PitchDiameter/Tooth Size Radio Buttons](#).

Commonly used for metric-based gears, this field specifies the tooth size, by specifying the number of millimeters of pitch diameter per tooth (that is, pitch diameter in millimeters divided by the number of teeth). Module times Pi is the number of millimeters of circumference (of the pitch circle) per tooth.

If you use this field, the pitch diameter is set to halfway between **Min Diameter** and **Max Diameter** (see [Min Diameter](#) and [Max Diameter](#)).

See [Pitch Diameter](#) for information on pitch diameters and pitch circles.

Pitch Diameter

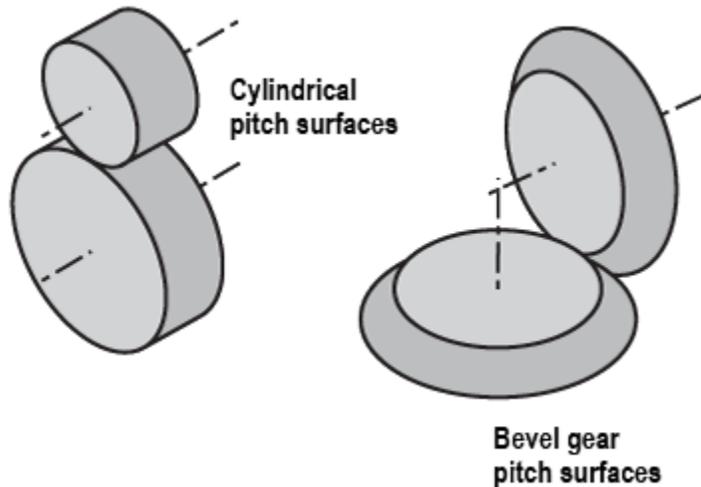
Displayed only if the **Input Pitch Diameter** radio button is selected. See [PitchDiameter/Tooth Size Radio Buttons](#).

This field specifies the diameter of a pitch circle. The pitch diameter cannot usually be directly measured on a gear, but it serves as the basis for many calculations. If you use this field, tooth size is the pitch circle circumference (Pi times the pitch diameter) divided by the number of teeth (see [Number of Teeth](#)).

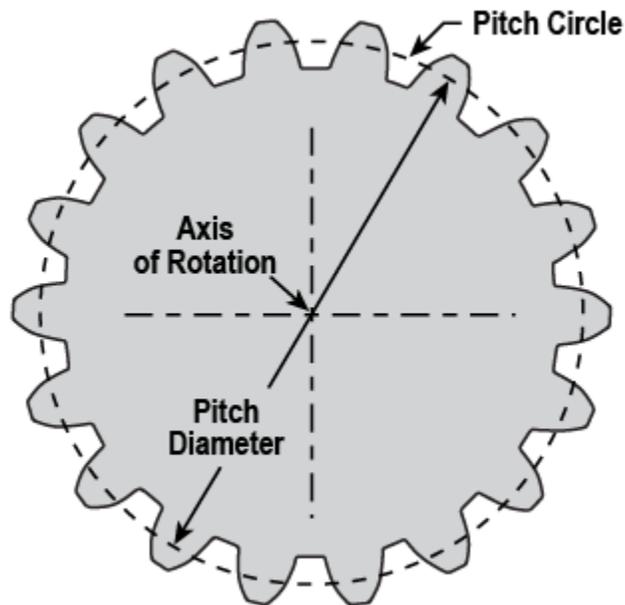
A warning is displayed in the dialog if you specify a value that is not between **Min Diameter** and **Max Diameter** (see [Min Diameter](#) and [Max Diameter](#)).

Pitch circle can be defined in terms of pitch surfaces as follows:

- The pitch surfaces of mating gears are the imaginary surfaces that roll together without slipping when the gears turn. Pitch surfaces are cylinders for spur and helical gears, and they are (truncated) cones for bevel gears.



- A pitch circle is formed from the intersection of the gear's pitch surface and a plane normal the gear's axis of rotation. If the pitch surface is a cone, the pitch circle is the largest circle formed from the intersection of the gear's pitch surface and some plane normal the gear's axis of rotation (that is, the circle that forms the base of the pitch cone).

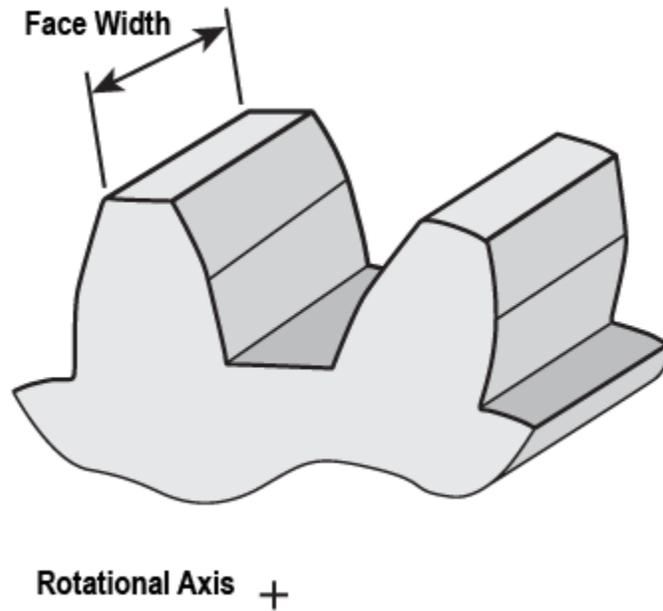


Note that diametral pitch is the number of teeth per inch of pitch diameter (that is, the number of teeth divided by the pitch diameter in inches). Pi divided by diametral pitch is circular pitch (the arc distance along a pitch circle between corresponding points of adjacent teeth).

aPriori estimates pitch diameter as the halfway diameter between minDiameter and maxDiameter. The User must override this value to get a more accurate dimension.

Face width

For spur and helical gears, this is the width of the gear in the axial direction.



For bevel gears, face width is the width of the gear in the axial direction divided by the cosine of the cone angle.

Pressure Angle

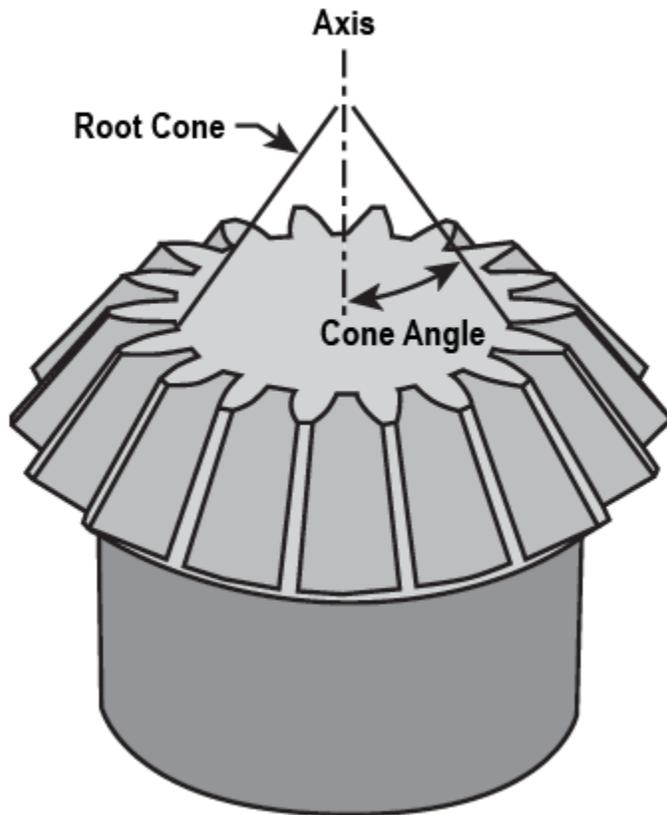
The pressure angle for mating gears is the acute angle between the line of action (the line of force between the gears) and a normal to the line connecting the gear centers.

The default value for this field is 14.5 degrees in aPriori baseline VPEs.

Cone Angle

Displayed only for bevel gears (see [Gear Type](#)). One half the apex angle of the gear's root cone.

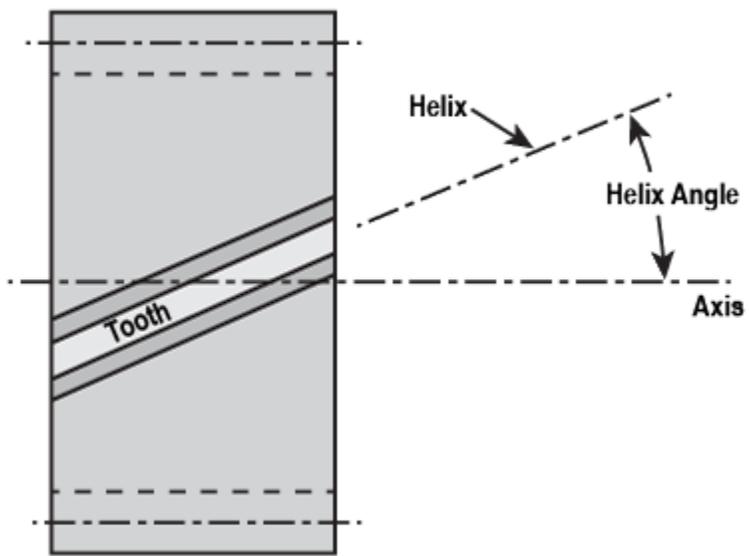
The gear's axis of rotation is the root cone's axis of symmetry. The surface of the root cone coincides with the bottoms of the tooth valleys.



Helix Angle

Displayed only for helical AxiGrooves.

Acute angle formed by the gear's helix and the axis of rotation.



Hand of Helix

Displayed only for helical AxiGrooves.

Handedness of helix, right or left.

Spiral Angle

Displayed only for spiral bevel gears.

Acute angle formed by the gear's spiral and the axis of rotation.

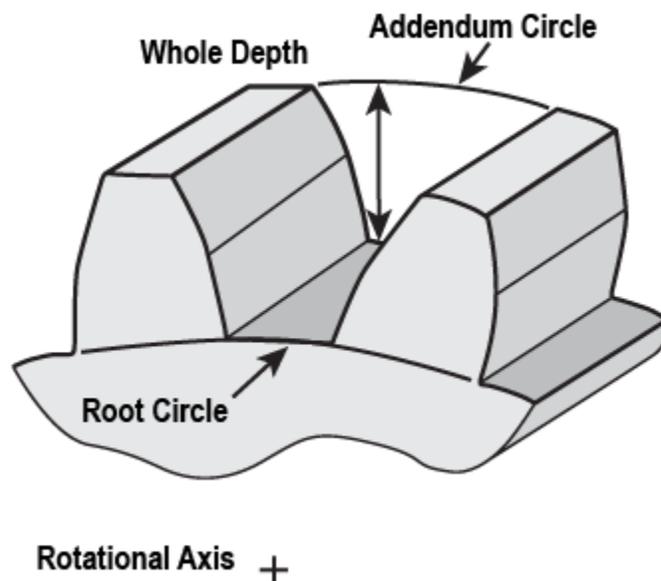
Hand of Spiral

Displayed only for spiral bevel gears.

Handedness of spiral, right or left.

Whole Depth

This is the distance, normal to the axis of rotation, from the root circle to the addendum circle. The root circle lies in a plane normal to the axis of rotation and coincides with the bottoms of the tooth valleys. The Addendum circle lies in a plane normal to the axis of rotation and coincides with the tops of the teeth.



If you modify **Whole Depth**, you must modify **Max Diameter** and/or **Min Diameter** accordingly:

$$\text{Whole Depth} = (\text{Max Diameter} - \text{Min Diameter}) / 2$$

See [Min Diameter](#) and [Max Diameter](#).

Quality System

Select one of the following:

- AGMA New Standard
- AGMA Old Standard

- **DIN**

AGMA New Standard is the default quality system for aPriori starting point VPEs.

Users of the Cost Model Workbench can modify the default quality system by modifying CSL in `axiGroovePostProcessor.csl` in the root cost model. Change

```
qualitySystem = GearQualitySystem.AGMA_New_Standard
```

to

```
qualitySystem = GearQualitySystem.AGMA_Old_Standard
```

or

```
qualitySystem = GearQualitySystem.DIN
```

Quality Level

Specify the required quality level. See [Process and Operation Routing and Feasibility](#) for information on how quality level affects process routing.

Possible quality values, from highest quality (top row) to lowest quality (bottom row), are as follows:

AGMA New Standard	AGMA Old Standard	DIN
A2	Q15	2
A3	Q14	3
A4	Q13	4
A5	Q12	5
A6	Q11	6
A7	Q10	7
A8	Q9	8
A9	Q8	9
A10	Q7	10
A11	Q6	11
A12	Q5	12

Max Diameter

For external gears, this is the diameter of the largest circle (in a plane normal to the axis) that coincides with the tops of the teeth.

For internal gears, this is the diameter of the largest circle (in a plane normal to the axis) that coincides with the bottoms of the tooth valleys.

If you modify this field, you must modify **Min Diameter** and/or **Whole Depth** accordingly:

Whole Depth = (Max Diameter – Min Diameter) / 2

See also [Min Diameter](#) and [Whole Depth](#).

Min Diameter

For external gears, this is the diameter of the smallest circle (in a plane normal to the axis) that coincides with the bottoms of the tooth valleys.

For internal gears, this is the diameter of the smallest circle (in a plane normal to the axis) that coincides with the tops of the teeth.

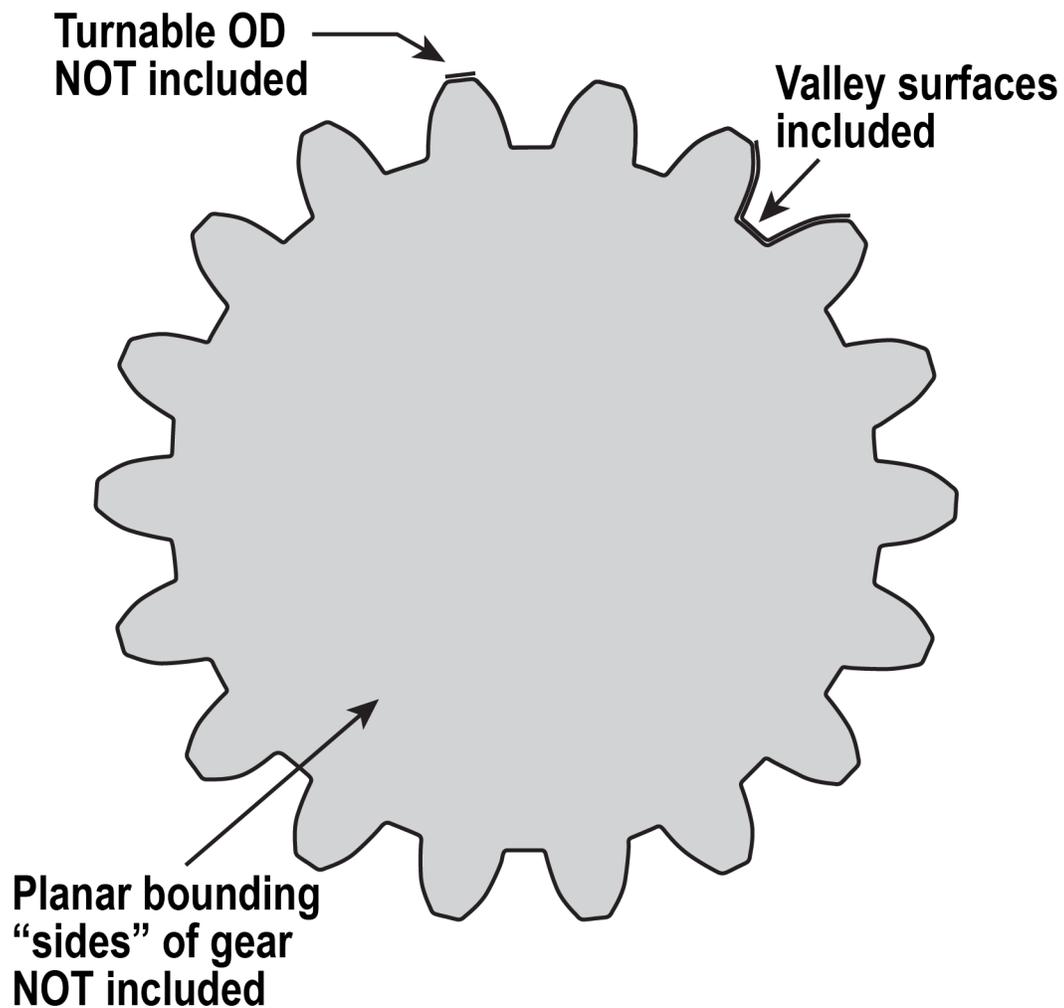
If you modify this field, you must modify **Max Diameter** and/or **Whole Depth** accordingly:

Whole Depth = (Max Diameter – Min Diameter) / 2

See also [Max Diameter](#) and [Whole Depth](#).

AxiGroove Geometric Properties

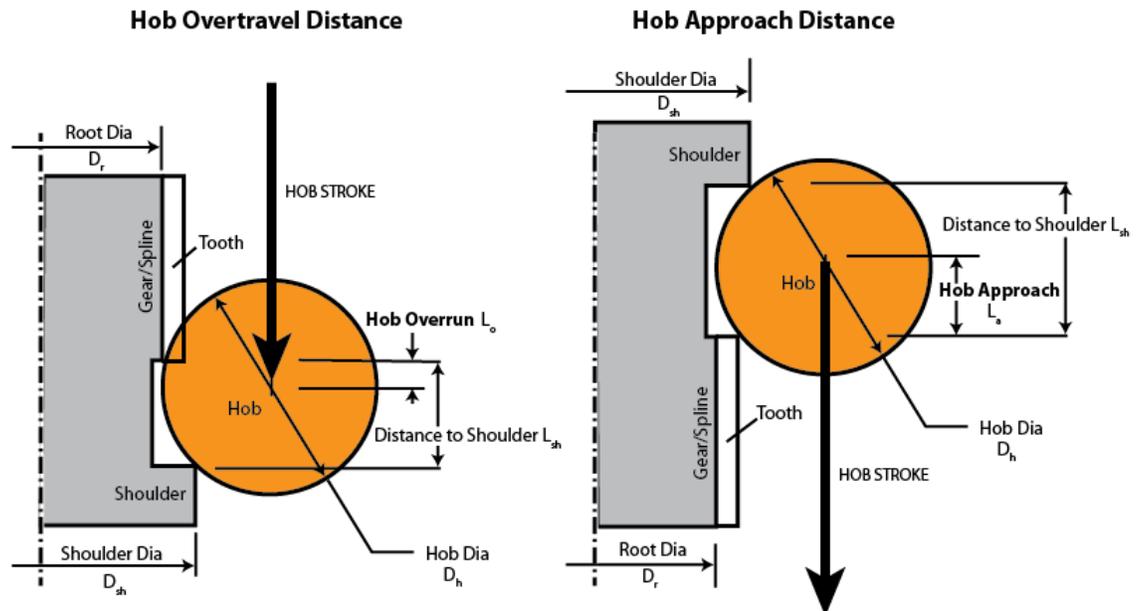
Child GCDs of an AxiGroove include the bottoms and sides of the tooth valleys. They do not include the tops of the teeth, and they do not include surfaces normal to the axis of rotation; so the cost of such surfaces is not included in the cost of an AxiGroove.



Extracted geometric AxiGroove properties include the following:

- **Approach From**: direction of approach of the machine tool: OD (from the outside), ID (from the inside), or NONE.
- **Artifact Key**: unique identifier.
- **Axial Length**: length of the AxiGroove along turning axis.
- **Cone Angle** cone angle of the AxiGroove in degrees. This is one half the apex angle of the AxiGroove's root cone. (The gear's axis of rotation is the root cone's axis of symmetry. The surface of the root cone coincides with the bottoms of the tooth valleys.) The angle is 0 for cylindrical AxiGrooves, positive for conical AxiGrooves, and -1 if the valley profile is not cylindrical or conical.
- **Distance To Shoulder A**: distance to the shoulder along the turning axis (in direction A). For external AxiGrooves, this is the distance between the end of the AxiGroove and the closest point on the turning profile that is higher than the valleys between teeth. For internal AxiGrooves, it is the distance to the closest

point on the turning profile that is lower than the tooth valleys. A dash, -, is displayed when there is no shoulder.



- **Distance To Shoulder B:** distance to the shoulder along the turning axis (in direction B). For external AxiGrooves, this is the distance between the end of the AxiGroove and the closest point on the turning profile that is higher than the valleys between teeth. For internal AxiGrooves, it is the distance to the closest point on the turning profile that is lower than the tooth valleys. It is -1 when there is no shoulder.
- **Groove Depth:** depth of the grooves.
- **Helix Angle:** helix angle of the AxiGroove in degrees. This is positive for right-handed AxiGrooves, and negative for left-handed AxiGrooves.
- **Helix Total Twist Angle:** total twist of the AxiGroove in degrees. This is set to -1 when either of the following holds:
 - AxiGroove's inner surface is neither cylindrical nor conical.
 - For external AxiGrooves, the bottom groove points are not on a spiral; for internal AxiGrooves, the top groove points are not on a spiral.
- **Max Diameter:** maximum diameter of the AxiGroove. This is twice the maximum distance from a tooth or valley surface to the turning axis.
- **Min Diameter** minimum diameter of the AxiGroove. This is twice the minimum distance from a tooth or valley surface to the turning axis.
- **Number of Teeth:** number of teeth in the AxiGroove.
- **Radial Undercut Volume Ratio:** ratio of the radial undercut volume to the whole volume of the AxiGroove.
- **Shoulder Diameter A:** diameter of the shoulder in direction A. For external AxiGrooves this is the largest diameter of the turning profile on one side of the AxiGroove. For internal AxiGrooves it's the smallest diameter. This is -1 for AxiGrooves with no shoulder.

- **Shoulder Diameter B:** diameter of the shoulder in direction B. For external AxiGrooves this is the largest diameter of the turning profile on one side of the AxiGroove. For internal AxiGrooves it's the smallest diameter. This is -1 for AxiGrooves with no shoulder.
- **Surface Area:** area of all grooves. This is the area of the walls and bottoms of the tooth valleys. It excludes the area of the tooth faces.
- **Tooth To Valley Volume Ratio:** ratio of tooth volume to valley volumes.
- **Valley Axial Extent :** axial length of valley extent. This is the total length of all inner faces of the axigroove adjacent to the turnable (recognized) surfaces.
- **Volume:** volume of axigroove.

Process and Operation Routing and Feasibility for Gears

The processes listed below are the specialized AxiGroove-making processes. These processes can be included in turning routings, following a lathe or mill turn process. Each process has a single operation, Setup, associated with the component GCD, and one or two operations associated with the AxiGroove GCD. Following are the AxiGroove operations by process:

- Bevel Gear Cutting Machine
 - Spiral BG Face Milling
 - Straight BG Face Milling
- Broach
 - Internal Gear Broaching
 - External AxiGroove Broaching
- Spline Roller
 - Spline Rolling
- Hob Machine
 - Hobbing
- Shaper
 - Shaping
- Shaver
 - Shaving

The processes listed below are the AxiGroove-finishing processes. Each process has a single operation, Setup, associated with the component GCD, and a single operation associated with the AxiGroove GCD. Following are the AxiGroove operations by process:

- Threaded Wheel Grinder
 - Threaded Wheel Grinding
- Profile Grinder
 - Profile Grinding

Routings for the specialized AxiGroove-making processes are determined as follows:

- Spiral bevel gears must be routed to the Bevel Gear Cutting Machine.

- Internal gears and internal splines are routed to the Broach, unless a shoulder interferes with tool access to the AxiGroove, in which case the Shaper process is used.
- External splines use the Spline Roller process, unless one of the following is the case:
 - Part is too big
 - Material is too hard (see Spline Roller in this section below)
 - Pressure angle is too shallow
 - Teeth are too big

If one or more of the above holds, the Hob Machine process is used if feasible (otherwise the Shaper process is used).

- External gears (other than bevel gears) and sprockets use the Hob Machine process, unless one or more shoulders come too close the AxiGroove, in which case the Shaper process is used. The Shaver process optionally follows hobbing (see Shaver in this section below).

Flutes and gears of unknown type are routed to milling processes that are not specific to gear making (so specialized gear-making tools and tool paths are *not* used in this case).

Finishing operations are used when quality requires them.

Heat Treatment is turned on to Carburizing when at least one AxiGroove exists on the part and when carburizing is generally recommended for the material type.

Following are the process and operation feasibility requirements:

- Bevel Gear Cutting Machine: AxiGroove must be a bevel gear.
- Internal Gear Broaching: the AxiGroove must be one of the following:
 - Internal spur gear
 - Internal helical gear
 - Internal spline

There must be no shoulders that obstruct tool access, that is, there must be a clear line of sight through the gear valley and the rest of the part.

- External AxiGroove Broaching: geometry can be generated by extruding the tooth/valley profile in a straight direction (geometric property **isStraighExtrude** is **true**).
- Spline roller: AxiGroove must be all of the following:
 - External spline
 - Not too big—its diameter must not exceed the machine property **maxSplineDiameter**.
 - Tooth size and pressure angle must be in range, as controlled by the cost model variables **splineRollingMaxModule** and **splineRollingPressureAngle**.
 - Made from material that is rollable (specified by cut code family in the lookup table **tblSplineRolling**) and not too hard (specified by the cost model variables **rollabilityBrinellThreshold**, **rollabilityRockwellICThreshold**, **rollabilityTensileStrengthThreshold**).
- Hob machine: AxiGroove must be one of the following:
 - External spur gear

- External helical gear
- External spline
- Sprocket

There must be no shoulders that obstruct hob approach and overtravel.

- Shaver: AxiGroove must be one of the following:

- External spur gear
- External helical gear

Either the number of hob starts must be greater than one or the AxiGroove must have DIN quality 6 or 7 (or their equivalent), by default. This can be configured as followed:

- VPE administrators can configure the required quality with the **Must Shave** column of the lookup table **tblGearQuality**.
- Number of hob starts (parallel helices of hob teeth) ranges between one helix (best quality and slowest cycle time) and three helices (poorest quality and fastest cycle time).

- Shaper: AxiGroove must be one of the following:

- External spur gear
- Internal spur gear
- External helical gear
- Internal helical gear
- Internal spline
- External spline

aPiori assumes that a gutter for chip evacuation is provided for any gears with zero shoulder distance on one side.

- Threaded Wheel Gear Grinder: AxiGroove must be one of the following:

- External spur gear
- External helical gear
- Sprocket

All the following must hold:

- AxiGroove must have DIN quality 2, 3, 4, or 5 (or their equivalent), by default. VPE administrators can configure the required quality with the **Must Grind** column of the lookup table **tblGearQuality**.
- The AxiGroove's Max Diameter must not exceed the value of the cost model variable **TWGMaxDiameterThreshold** (1200mm by default).
- The production volume must not be less than the value of the cost model variable **TWGProductionVolumeThreshold** (150 by default).
- There must be no shoulders that obstruct grinding wheel access.

- Profile Gear Grinder: AxiGroove must be one of the following:

- External spur gear
- External helical gear
- Sprocket

Both the following must hold:

- AxiGroove must have DIN quality 2, 3, 4, or 5 (or their equivalent), by default. VPE administrators can configure the required quality with the **Must Grind** column of the lookup table **tblGearQuality**.
- There must be no shoulders that obstruct grinding wheel access.

Site Variables for Gears

Following are among the site variables related to AxiGrooves:

- **axigrooveExtractionEnabled**, which allows you to disable and enable AxiGroove extraction. See [Disabling and Enabling AxiGroove Extraction](#).
- Variables that allow you to control what geometry extraction recognizes as an AxiGroove. See [Controlling What Gets Recognized as an AxiGroove](#).

See also [Additional Site Variables](#).

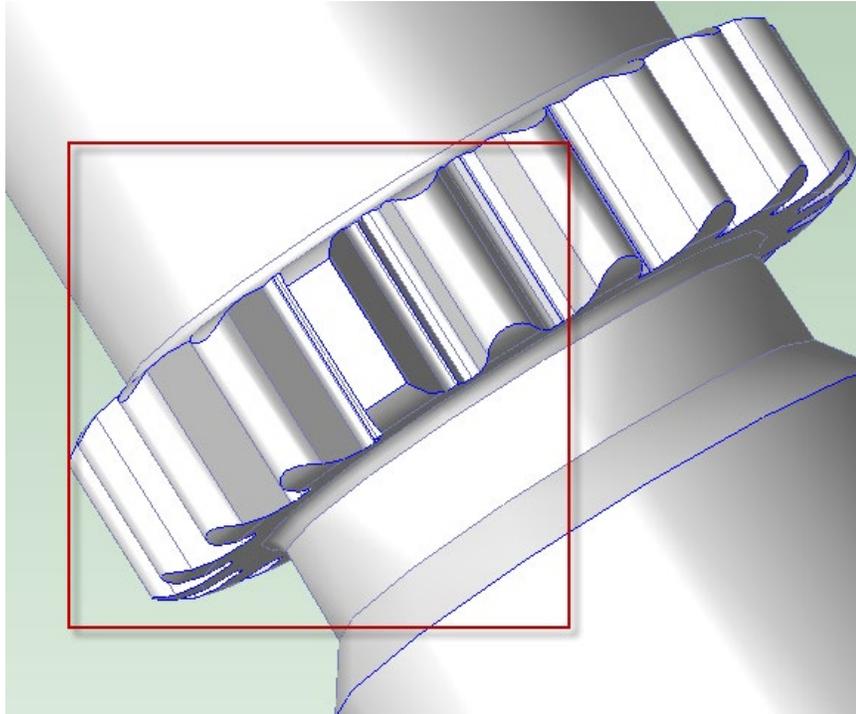
Disabling and Enabling AxiGroove Extraction

In some situations, you might want to disable AxiGroove extraction for all the VPEs at a given stie. For example, if your company does not make gears, but makes many parts with radially symmetric features that can be confused with gears, you should disable AxiGroove extraction. You can disable AxiGroove extraction by setting to **false** the site variable **axigrooveExtractionEnabled**. This variable is set to **true** by default.

Controlling What Gets Recognized as an AxiGroove

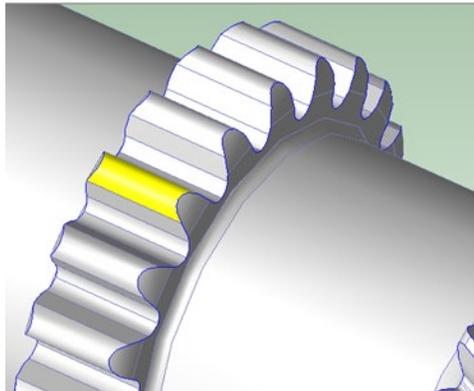
When AxiGroove extraction is enabled, aPriori recognizes as AxiGrooves patterns of grooves that meet the following requirements:

- GCD is fully symmetric with respect to an axis. There is no variation among teeth or among valleys; that is, each tooth is just the same as every other tooth, and each valley is just the same as every other valley. For example, the following is *not* recognized as an AxiGroove:



Note that partial or sector gears are not recognized as AxiGrooves.

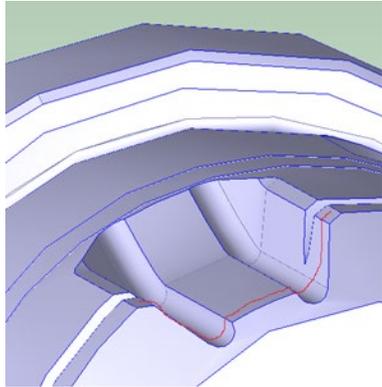
- Outside of the GCD must be turnable. The intersection of the tops of the teeth with a plane orthogonal to the turning axis must consist of arcs lying on a circle. In some cases, if the tops of the teeth are planar, the GCD *is* recognized as an AxiGroove. If the tops of the teeth are tangent to a circle, the GCD is *not* recognized as an AxiGroove. For example, the following is *not* recognized as an AxiGroove:



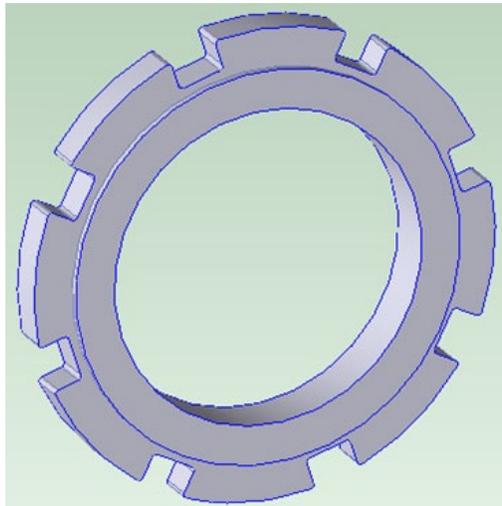
The turnability requirement implies that the tops and valleys must be modeled by separate surfaces.

- For at least half of the GCD's length, the bottom-most points of each valley must lie on an imaginary cylinder or cone. For example, for non-helical gears, in a longitudinal cross-section (that is, cross-section in which the turning axis is a line), each valley's bottom is a line. If there are longitudinal bulges, the GCD is generally not recognized as an AxiGroove. aPriori does recognize some AxiGrooves with sufficiently mild valley bulges, as specified by the plant variable **axigrooveBulgeOutProfileToleranceFactor**, which defaults to 0.4.

The following is *not* recognized as an AxiGroove:



- Tooth-to-valley volume ratio is within range (0.25 to 3.0, by default). The plant variables **axigrooveMinToothToValleyVolumeRatio** and **axigrooveMaxToothToValleyVolumeRatio** specify the minimum and maximum values for tooth volume divided by valley volume. A value of -1 for the maximum value indicates that there is no maximum. A minimum value that exceeds the maximum value indicates that there is no minimum. For example, the following is *not* recognized as an AxiGroove by default:



- Valley width-to-depth ratio is within range (0.25 to 3.0, by default). The plant variables **axigrooveMinValleyWidthToDepthRatio** and **axigrooveMaxValleyWidthToDepthRatio** specify the minimum and maximum values for tooth volume divided by valley volume. A value of -1 for the maximum value indicates that there is no maximum. A minimum value that exceeds the maximum value indicates that there is no minimum.

See also [Additional Site Variables](#).

Additional Site Variables

Additional AxiGroove site variables include the following:

- **axigrooveHeliToothProfileToleranceFactor** (default: 0.2)
- **axigrooveHelixSamplingDepth** (default: 0.5)
- **axigrooveMinNumberOfTeeth** (default: 4)

- **axiGrooveStraightToothProfileToleranceFactor** (default: 0.07)

Cost Model Variables for Gears

AxiGroove-related cost model variables include the following:

- **defaultPressureAngle**: default pressure angle in degrees. Default: 14.5 degrees.
- **gearQualityDefaultAgmaNewStd**: default quality for AGMA New Standard. Default: A8.
- **gearQualityDefaultAgmaOldStd**: default quality for AGMA New Standard. Default: Q8.
- **gearQualityDefaultDinStd**: default quality for AGMA New Standard. Default: 9.
- **TWGMaxDiameterThreshold**: diameter threshold at or below which a gear is feasible for Threaded Wheel Grinding. Default: 1200mm.
- **TWGProductionVolumeThreshold**: production volume threshold below which gears are feasible for Profile Grinding. Default: 150
- **defaultNumStarts**: default number of starts (parallel rows of hob teeth) on a gear making hob. Default: 1.
- **maxAxiGrooveMillingTime**: maximum cycle time in seconds for general gear roughing or finishing of an AxiGroove. Default: 10,800 seconds.
- **maxShavingWorkpieceSpeed**: absolute maximum rotational speed (in RPM) of shaving workpiece regardless of the machine selection. Default: 1000 RPM.
- **minNumTeethForMultistart**: minimum number of teeth on a gear in order to use multiple hob starts. Default: 12.
- **numDwellsPerShapingStroke**: number of dwells per each shaping stroke. Default: 12.
- **numTeethPerRevolution**: default number of teeth per revolution used to calculate the number of hob starts in Gear Grinding. Default: 24.
- **plungeShavingDwellCoeff**: an empirical coefficient for the calculation of plunge shaving dwell time. Typically it is between 20 and 70. Default: 45.
- **rollabilityBrinellThreshold**: spline materials above this hardness threshold are not roll-able. Default: 700.
- **rollabilityRockwellCThreshold**: spline materials above this hardness threshold are not roll-able. Default: 63.
- **rollabilityTensileStrengthThreshold**: spline materials above this hardness threshold are not roll-able. Default: 300.
- **shaperStrokeLengthRatio**: ratio of the shaper stroke length to the face width of the AxiGroove. Default: 1.15.
- **shapingDwellTimePerStroke**: time in seconds for the tool dwell time in shaping. Default: 0.15 seconds.
- **spiralBevelCutterDiameterRatio**: ratio of the cutter diameter to the pitch diameter for spiral bevel gears. Default: 1.

- **splineHobbingFeedFactor**: adjustment factor that reduces tool feed for spline hobbing. Default: 0.5.
- **splineRollingMaxModule**: tooth module at which spline rolling becomes infeasible. Default: 1.6.
- **splineRollingPressureAngle**: angle below which spline rolling is feasible. Default: 20.
- **threadedGrindingWheelDressTime**: typical time in seconds required to touch-up dress a threaded grinding wheel for Gear Grinding. Assumes that wheel has been pre-dressed. Default: 900 seconds.

Setup Options for Gears

AxiGroove-related setup options include the following:

Hob Machine and Shaver

- Hobbing and Shaving:
 - Number of Starts: Number of hob starts (parallel helices of hob teeth), which ranges between one helix (best quality and slowest cycle time) and three helices (poorest quality and fastest cycle time).

The default is 1, if the AxiGroove's number of teeth is less than the cost model variable **minNumTeethForMultistart**. Otherwise, the default is 3, if **defaultNumStarts** is greater than or equal to 3 and the number of teeth is not divisible by 3. Otherwise, the default is 2, if **defaultNumStarts** is greater than or equal to 2 and the number of teeth is not divisible by 2. Otherwise the default is 1.

See also the Shaver process in [Process and Operation Routing and Feasibility for Gears](#), as well as **defaultNumStarts**, **minNumTeethForMultistart**, and **numTeethPerRevolution** in [Cost Model Variables](#).

Bevel Gear Cutting Machine

- Spiral BG Face Milling
 - Cutting Speed
 - Feed Per Tooth
 - Blades Per Side
 - Cutter Diameter
- Straight BG Face Milling
 - Cutting Speed
 - Feed Per Tooth
 - Blades Per Side
 - Cutter Diameter
- Setup
 - Repetitions Of Part Setup
 - Total Part Setup Time
- Process-level options
 - Batch Setup Time

- Fixture Cost
- Hard Tooling Cost
- NC Programming Cost
- Tool Count
- Parts In Pallet
- Install Workholder
- Cleanup Time

Broach

- Broaching
 - Cutting Speed
 - Return Speed
 - Rough Tooth Pitch
 - Finish Tooth Pitch
 - Rough Feed
 - Finish Feed
 - Start/Stop Time
- Setup
 - Repetitions Of Part Setup
 - Total Part Setup Time
- Process-level options
 - Batch Setup Time
 - Fixture Cost
 - Hard Tooling Cost
 - NC Programming Cost
 - Tool Count
 - Parts In Pallet
 - Install Workholder
 - Cleanup Time

Hob Machine

- Hobbing
 - Tool Type
 - Tool Series
 - Unit System
 - Tool Diameter
 - Tool Feed
 - Tool Cutting Speed
 - Hob Helix Angle
 - Tool Axis Speed
 - Engagement Time
- Setup

- Repetitions Of Part Setup
- Total Part Setup Time
- Process-level options
 - Batch Setup Time
 - Fixture Cost
 - Hard Tooling Cost
 - NC Programming Cost
 - Tool Count
 - Parts In Pallet
 - Install Workholder
 - Cleanup Time

Profile Gear Grinder

- Profile Grinding
 - Total Grind Length
 - Grind Time Per Flank
 - Number of Rough Grinding Passes
 - Number of Finish Grinding Passes
 - Number of Starts
 - Table Feed
 - Machine Index Time
 - Part Approach Time
 - End of Pass Dwell Time
 - Wheel Dress Time
 - Grinding Wheel Change Time
 - Workpiece Index Method
 - Down Feed Method
 - Gear Flank Grinding Method
 - Engagement Time
- Setup
 - Repetitions Of Part Setup
 - Total Part Setup Time
- Process-level options
 - Batch Setup Time
 - Fixture Cost
 - Hard Tooling Cost
 - NC Programming Cost
 - Tool Count
 - Parts In Pallet
 - Install Workholder
 - Cleanup Time

Shaper

- Shaping
 - Rapid Transfer Time
 - Cut 1 Stroke Rate
 - Cut 2 Stroke Rate
 - Cut 3 Stroke Rate
 - Cut 1 Radial Feed per Stroke
 - Cut 2 Radial Feed per Stroke
 - Cut 3 Radial Feed per Stroke
 - Cut 1 Rotary Feed per Stroke
 - Cut 2 Rotary Feed per Stroke
 - Cut 3 Rotary Feed per Stroke
- Setup
 - Repetitions Of Part Setup
 - Total Part Setup Time
- Process-level options
 - Batch Setup Time
 - Fixture Cost
 - Hard Tooling Cost
 - NC Programming Cost
 - Tool Count
 - Parts In Pallet
 - Install Workholder
 - Cleanup Time

Shaver

- Shaving
 - Number of Shaving Strokes
 - Cutting Speed
 - Feed per Revolution
- Setup
 - Repetitions Of Part Setup
 - Total Part Setup Time
- Process-level options
 - Batch Setup Time
 - Fixture Cost
 - Hard Tooling Cost
 - NC Programming Cost
 - Tool Count
 - Parts In Pallet
 - Install Workholder

- Cleanup Time

Spline Roller

- Spline Rolling
 - Cycle Time
- Setup
 - Repetitions Of Part Setup
 - Total Part Setup Time
- Process-level options
 - Batch Setup Time
 - Fixture Cost
 - Hard Tooling Cost
 - NC Programming Cost
 - Tool Count
 - Parts In Pallet
 - Install Workholder
 - Cleanup Time

Threaded Wheel Gear Grinder

- Threaded Wheel Grinding
 - Total Grind Length
 - Grind Time Per Flank
 - Number of Rough Grinding Passes
 - Number of Finish Grinding Passes
 - Number of Starts
 - Table Feed
 - Part Approach Time
 - End of Pass Dwell Time
 - Wheel Dress Time
 - Grinding Wheel Change Time
 - Down Feed Method
 - Threaded Wheel Helix Angle
 - Grinding Wheel Diameter
 - Tool Axis Speed
 - Engagement Time
- Setup
 - Repetitions Of Part Setup
 - Total Part Setup Time
- Process-level options
 - Batch Setup Time
 - Number of Part Setups
 - First Part Setup Time

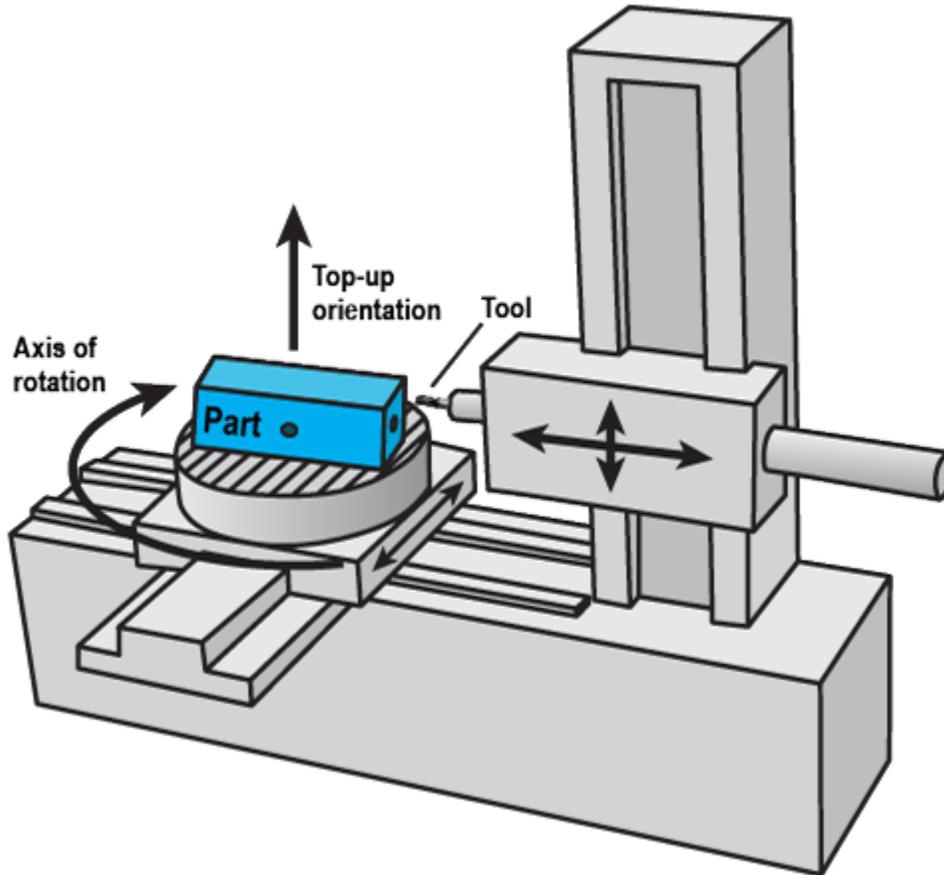
- Subsequent Part Setup Time
- Fixture Cost
- Hard Tooling Cost
- NC Programming Cost
- Tool Count
- Parts In Pallet
- Install Workholder
- Cleanup Time

3-Axis Mill

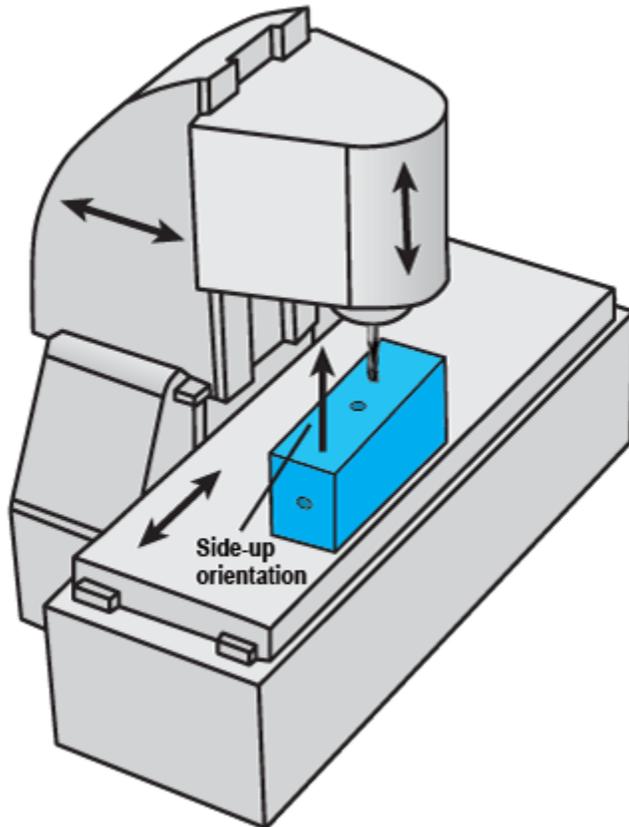
- General Mill Roughing
 - Material Removal Rate
 - Tool Diameter, mm
 - Tool Cutting Speed, m/min
 - Requested Feed Per Tooth, mm/tooth
 - Number Of Teeth
 - Axial Cut Depth, % Of Tool Diameter (0 - 100)
 - Radial Cut Depth, % Of Tool Diameter (0 - 100)

Working with Part Setups and SetupAxis GCDs

Part setup is the task of orienting, aligning, and clamping a part on a machine so that a particular operation or sequence of operations can be performed on it. (Note that part setup is different from batch setup, which must be performed once for every manufacturing run of a set of identical parts.) Consider, for example, a shoe-box shaped part that has a top, a bottom, and four sides, and suppose there is a hole in each of the four sides. For a machine whose tool approaches horizontally, making this part's holes requires a top-up or bottom-up orientation. On a 4-axis mill, which can rotate the part around a vertical axis (as well as translate the tool along three dimensions), a single setup (such as top up) can be used to make all four holes. Different rotations of the part make different holes accessible to the tool.



On a 3-axis mill (which cannot rotate the part) whose tool approaches vertically, making one of this part's holes requires the part to be oriented with the side that contains the hole facing up, so that the hole is accessible to the tool. Each hole requires a different orientation, or setup.



When aPriori costs a part for a particular routing, it takes into account part setup costs. aPriori includes in the fully burdened cost the labor and overhead cost to re-orient, correctly align, and re-clamp the part for each setup that the routing requires. It also takes into account setup requirements when determining operation feasibility. For example, if an operation on a surface requires a dedicated setup (a setup that is not used by any other operation), that operation is sometimes deemed infeasible. The feasibility rules help aPriori to choose the best operation sequences with the fewest setups for a given part and process routing.

More information about setups is contained in the following sections:

- [Setup Operations](#)
- [Setup Axis GCDs](#)
- [Principal Setup Axes](#)
- [Rotational Setup Axes](#)
- [System-activated and User-activated Setup Axes](#)
- [Turning Axes](#)
- [Displaying Setups, Associated Operations, and GCDs](#)

See also [Setup Axes and Operation Feasibility](#) for more information on how aPriori chooses operation sequences and setups.

See [Setup Operation Times and Costs](#) for more information on how aPriori determines setup costs.

Setup Operations

aPriori models the procedure of orienting, aligning, and clamping a part as an operation named **Setup**, which is performed on the Component GCD. If a part requires multiple setups, it will have multiple child setup operations, **Setup**, **Setup:1**, **Setup:2**, and so forth. In the Manufacturing Process pane, you can expand a setup operation to see the operations that are performed while the part is in the orientation established by the setup.

See [Setup Operation Times and Costs](#) for more information on how aPriori determines setup costs.

Note that the cost model relies on a *node occurrence generator* Java plugin (specified by the node attribute **generatorName**) to group operations by setup. See *Working with Zero-or-More Nodes* in the Cost Model Workbench Guide for more information.

Setup Axis GCDs

For machined parts, the Geometric Cost Drivers pane displays a group of special GCDs, setup axes, named **SetupAxis:1**, **SetupAxis:2**, **SetupAxis:3**, and so forth. They appear under **Setup Axes/Candidates**, which appears under **Component**. Each setup axis listed in the Geometric Cost Drivers pane represents a direction in the coordinate system of the part, that is, a part-relative direction (such as top-wards).

Setup axes differ from other kinds of axes (such as a GCD's axis of symmetry or a part's turning axis) in an important respect: whereas other types of axes are lines (with a specific location) in the coordinate system of the part, setup axes indicate only directions in the coordinate system of the part. A direction can be thought of as an equivalence class of co-directional lines, or alternatively as a unit vector extending from the origin of the part's coordinate system.

Setup axis GCDs serve two purposes:

- To represent candidate part orientations (that is, possible orientations of the part with respect to the machine that it is clamped to). See [Part Orientations](#).
- To represent candidate tool orientations (that is, possible cutting tool approaches with respect to one or more part GCDs. See [Tool Orientations](#).

aPriori creates setup axis GCDs to represent every potentially useful setup orientation and every direction from which a tool might usefully approach a GCD in order to machine it. (For each group of planar faces that face the same direction, it creates a setup axis normal to the planar faces in the group; for each group of curved walls whose rules run in the same direction, it creates a setup axis co-directional with the rules; and for each group of axisymmetric GCDs whose axes of symmetry run in the same direction, it creates a setup axis to specify that direction as well. Additional setup axes are created for other GCDs if necessary.)

Tool Orientations

SetupAxis GCDs are used to represent part-relative directions from which a tool might possibly approach, that is, to represent how a tool might be oriented during the performance of an operation. Each setup axis listed in the Geometric Cost Drivers pane is a candidate tool orientation.

For each of a part's GCDs, and for each setup axis, aPriori extracts information about the accessibility of the GCD to a tool approaching from the direction represented by the

setup axis. This information appears in the Geometric Cost Drivers Pane under the GCD Relation **Is Accessible From**.

For example, suppose that the direction represented by **SetupAxis:1** is normal to **PlanarFace:1**, and suppose that a tool approaching from that direction has partially obstructed access to **PlanarFace:1**. Then the Geometric Cost Drivers pane will list an **Is Accessible From** relation that relates **SetupAxis:1** to **PlanarFace:1**, and whose **Direction Type** is **Normal Obstructed**.

aPriori uses this accessibility information to help determine whether it is feasible for a given type of machine to maneuver its cutting tools into position for a given operation. See [GCD Accessibility and Tool Orientations](#) for more information.

Part Orientations

SetupAxis GCDs are used to represent a part orientation that is established by an individual setup operation. Each setup operation in the Manufacturing Process pane is listed together with a setup axis—the name of the setup axis appears in parentheses next to the operation name.

A given SetupAxis GCD represents the orientation in which the setup axis (a part-relative direction) is co-directional with the machine's tool approach direction (the machine-relative direction from which the tool approaches).

An exception to this is a rotational setup axis for a 4-axis mill; in this case, the SetupAxis GCD represents the orientation in which the setup axis is parallel to the machine's axis of rotation—see [Setup Axes and Operation Feasibility](#) for more information. (Note that aPriori assumes that rotation about the machine's axis of rotation is not fast enough to support turning operations.)

For all the operations listed under the **Setup** operation, the part orientation specified by the associated setup axis allows the tool to perform the operations on the associated GCDs (the GCDs listed under the operations in the Manufacturing process pane).

For turning operations, aPriori represents the part orientation as a turning axis rather than a setup axis, describing whether the part is supported by its left hand side or its right hand side with respect to the turning axis. See [Turning Axes](#). (Note that rotation about a turning axis, unlike rotation about a 4- or 5-axis mill's axis of rotation, is assumed to be fast enough to support turning operations.)

Feasibility rules for non-turning operations typically attempt to select a setup axis that can render the current GCD accessible to the current operation. See [GCD Accessibility and Tool Orientations](#) and [GCD Accessibility and Setup Axes](#).

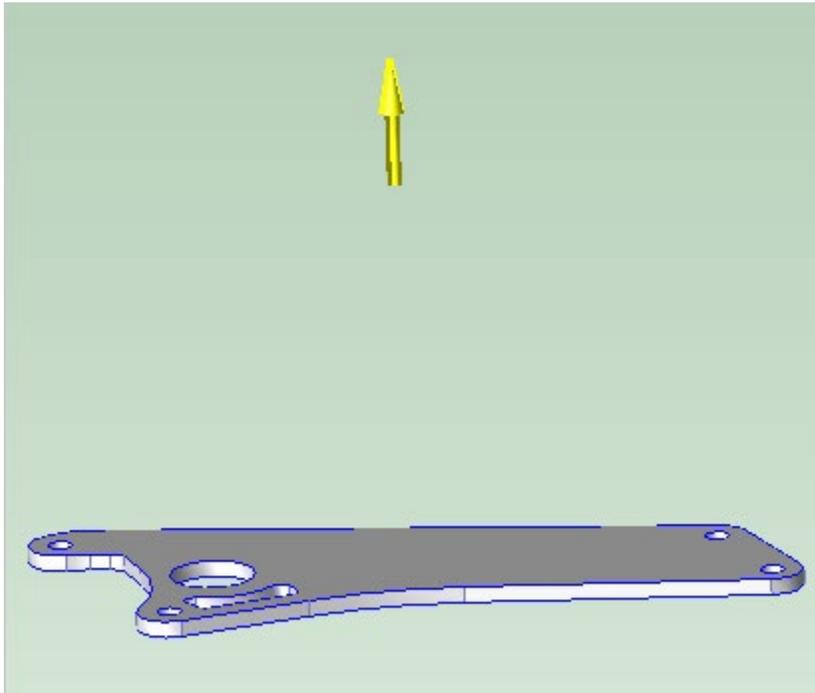
Principal Setup Axes

When aPriori analyzes a part and performs GCD extraction, it chooses certain orientations to serve as the *principal setups*. There are two principal setup axes, which have the values PRIMARY and SECONDARY, respectively, for the property **Setup Type**. The first principal setup orients the part top up, and generally allows operations to be performed on the top of the part, while the second principal setup orients the part top down, and generally allows operations to be performed on the bottom. (Sides of the part can also be accessed by tools approaching from the primary or secondary setups, or by additional setups.)

aPriori chooses principal setup axes by using a heuristic to choose a top for the part. Very roughly, the top is chosen so as to maximize the surface area accessible from directly above, when the part is upright (that is, when the part is oriented with the top up). The actual quantity maximized is a weighted sum of the surface areas of accessible GCDs, weighted by GCD type (for example, planar faces are weighted more than curved surfaces), as well as by accessibility type (for example, a normal-accessible planar face is weighted more than an oblique-accessible planar face).

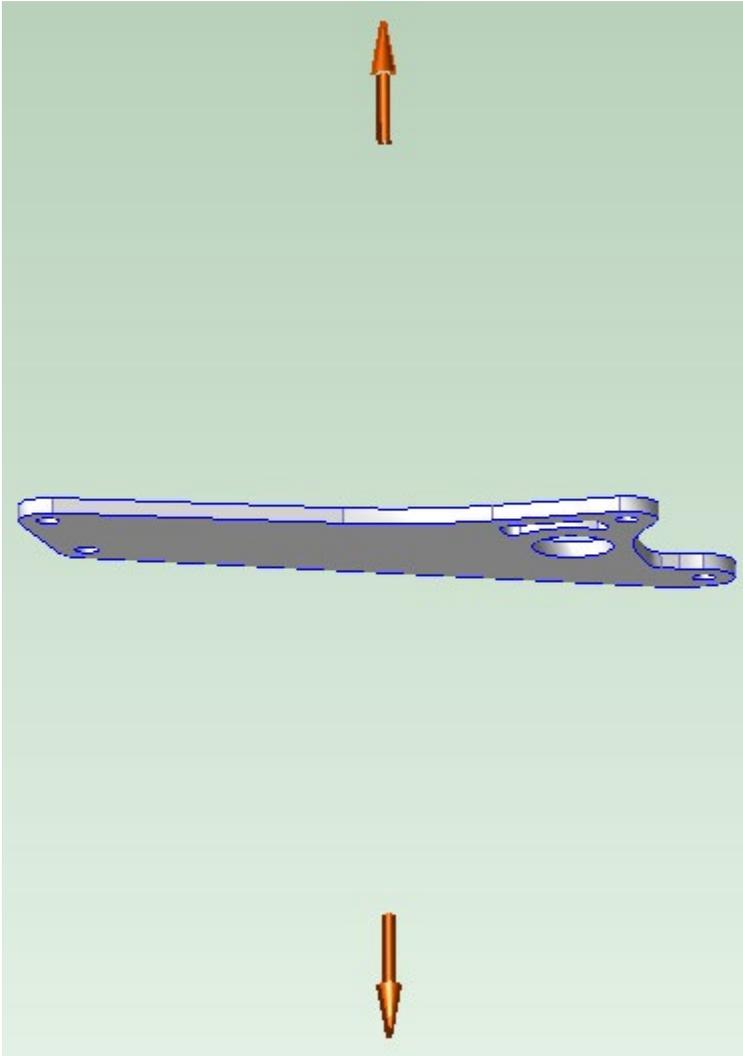
For rectangular machining stock, you can direct aPriori to choose the directions along the shortest stock dimension instead, by setting the site variable **useShortestStockDimentionForPrimarySetup** to **true**. In this case, aPriori chooses directions along the shortest dimension of the part's bounding box to serve as the principal setups. Of the two principal setup axes, the primary axis is the one that, roughly, maximizes the surface area it makes accessible. As with the default configuration, the actual quantity maximized is a weighted sum of the surface areas of accessible GCDs, weighted by GCD type, as well as by accessibility.

When aPriori chooses a primary setup axis, it is choosing a part-relative direction, top-wards. When you view a part in the component viewer, and select **SetupAxis:1** in the Geometric Cost Drivers pane, the viewer displays an arrow pointing top-wards.



The direction indicated by the arrow is the part's primary setup axis. It represents the way the part is oriented on a given machine when the setup axis points in the direction from which the tool approaches.

The part's secondary setup axis, **SetupAxis:2**, is bottom-wards, which points in the opposite direction.



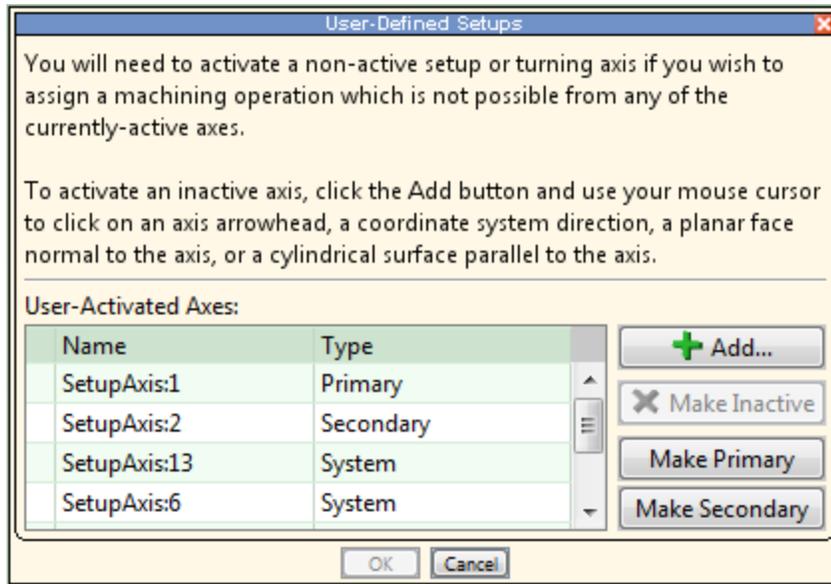
The primary and secondary setup axes (top-wards and bottom-wards) serve as the part's principal setup axes.

If you show active setup axes for a part (see [Displaying Setups, Associated Operations, and GCDs](#)), the component viewer displays the principal setup axes (as well as any other active setup axes—see [System-activated and User-activated Setup Axes](#)). You can override aPriori's choice of principal setup axes—see [Overriding Principal Setup Axes](#).

Overriding Principal Setup Axes

To override aPriori's choice of principal setup axes, follow these steps:

- 1 In the Viewer toolbar, Click the setup axis tool, , and select **User-Defined Setups...** from the popup menu. The User-Defined Setups dialog appears.



- 2 Select a setup axis in the **User-Activated Axes** table, and click **Make Primary** or **Make Secondary**.
- 3 Click **OK**.

Rotational Setup Axes

In addition to primary and secondary setup axes (see [Principal Setup Axes](#)) aPiori creates two rotational setup axes for use only with machines that have at least one rotational axis. They represent the way the part is oriented on a given rotational machine (such as a 4- or 5-axis mill) when the setup axis is parallel to the machine's axis of rotation.

For a 4-axis mill, the first rotational setup axis is chosen so as to maximize the number of features it makes accessible (that is, the first rotational setup axis is the setup axis that is normal to the greatest number of other setup axes). The other rotational axis is in a direction that is normal to the first rotational axis; aPiori chooses the normal whose name has the lowest numbered suffix (so, for example, if SetupAxis:4, SetupAxis:8, and SetupAxis:99 are all the normals to the first rotational setup axis, aPiori chooses SetupAxis:4 as the second rotational setup axis).

For a 5-axis mill, the two rotational setup axes have the same directions as the two principal setup axes; they are essentially copies of the primary axes.

Note that, for these rotational machines, the rotational motion differs from turning in these two respects:

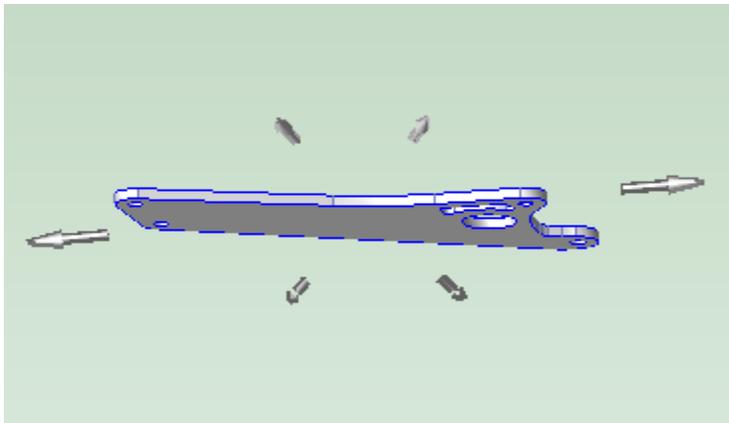
- The rotational motion is not fast enough to support turning operations.
- The rotational motion can stop at a precise angle of rotation.

Note also that, for a 4-axis mill, the tool approach is perpendicular to the rotational axis.

System-activated and User-activated Setup Axes

If a setup axis is not *activated*, it usually is not considered by aPiori when evaluating operation feasibility--see [Setup Axes and Operation Feasibility](#). Initially, only principal setup axes (see [Principal Setup Axes](#)) and setup axes appropriate for hole-making are activated (except during [Semi-automated Costing](#), when only principal and user-activated setup axes are ever activated). If you want aPiori to use a particular part orientation for one or more operations, you should activate the setup axis that represents that orientation. As with principal setup axes, a user-activated setup axis represents the way the part is oriented on a given machine when the setup axis points in the direction from which the tool approaches (or, for machines with an axis of rotation, such as a 4-axis mill, when the setup axis is normal to the direction from which the tool approaches--see [Part Orientations](#)).

If you show inactive setup axes for a part, the component viewer displays candidate setup axes that can be activated by clicking (see [Displaying Setups, Associated Operations, and GCDs and Activating Setup Axes](#)).



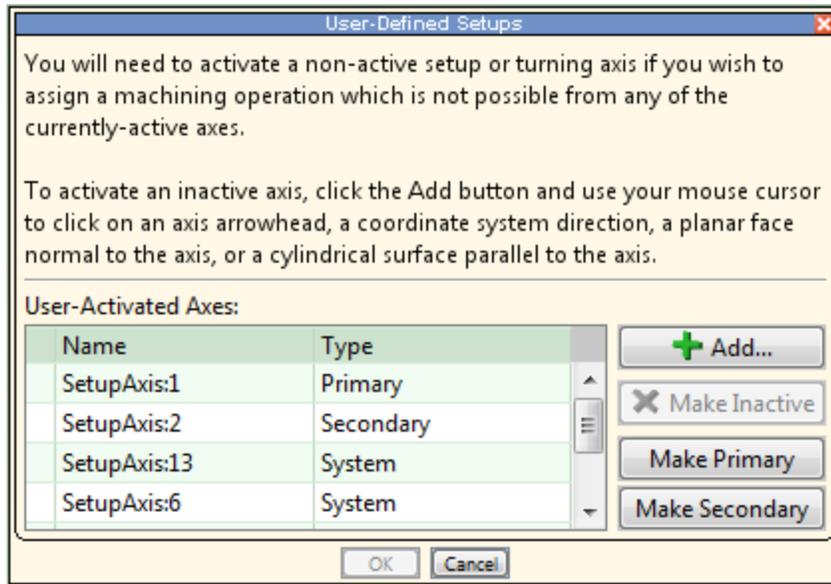
Activating Setup Axes

You can activate a setup axis in two ways:

- Globally, making it available for operations on all GCDs
- Locally, making it available only for operations on a specified GCD. A setup axis activated for a specific GCD is considered inactive by aPiori when it evaluates the feasibility of operations on other GCDs. Activate a setup locally, for a specific GCD, if you want to prevent the possibility of the setup being used for operations on other GCDs.

To globally activate an inactive setup axis, follow these steps:

- 1 In the Viewer toolbar, Click the setup axis tool, , and select **User-Defined Setups...** from the popup menu. The User-Defined Setups dialog appears.



- 2 Click the Add button. The cursor changes to the setup axis tool, .
- 3 In the Viewer, do one of the following:
 - o Click an arrowhead to activate the setup axis that the arrow represents.
 - o Click a planar face to activate a setup axis that is normal to the planar face.
 - o Click a cylindrical surface to activate a setup axis that is parallel to the cylinder's axis.

The selected axis turns blue, and its name appears in the User-activated Axes table.

- 4 Click **OK**.

To activate a setup axis locally, for specific GCD, follow these steps:

- 1 In the Viewer, select a GCD (so that it turns yellow), and then right-click the GCD and select **Assign Setup Axis...** from the context menu. The Viewer displays all the candidate setup axes, and the Assign Setup Axis dialog appears. The cursor, while over the Viewer, changes to the setup axis tool, .
- 2 In the Viewer, do one of the following:
 - o Click an arrowhead to activate the setup axis that the arrow represents.
 - o Click a planar face to activate a setup axis that is normal to the planar face.
 - o Click a cylindrical surface to activate a setup axis that is parallel to the cylinder's axis..

The selected axis turns blue, and its name appears in the Assign Setup Axis dialog.
- 3 Click **OK** in the Assign Setup Axis dialog.

Turning Axes

A turning axis in aPriori represents an axis of revolution for rotationally-symmetric features that may be machined by turning. For a turning machine (such as a lathe) it specifies a setup that orients the part so that the part's turning axis coincides with the machine's turning axis. Turning axes come in pairs; the axes in a pair coincide with one another and have opposite directions, and each represents a part-centric clamping direction, either left-end or right-end.

aPriori automatically creates candidate turning axes during geometry extraction. How many are automatically created depends on both the geometry of the current part and the current process group (see [System-created Turning Axes](#)). Users can request the creation of additional turning axis pairs by using the Modify Turning Axes dialog (see [User-defined Turning Axes](#)).

GCDs and turning axes are related by the **Is About** relation, displayed in the Geometric Cost Drivers pane.

System-created Turning Axes

For Bar and Tube parts, aPriori creates a pair of turning axes along the centerline of a round, square, or hex bar or tube. Turning is not supported for other types of bar and tube stock.

For stock machining, aPriori creates a turning axis pair along the centerline of a round bar or tube. You can also specify user-defined turning axes for round, square or rectangular stock—see [User-defined Turning Axes](#).

For other process groups, aPriori creates one or more candidate turning axis pairs, very roughly, by identifying a direction that is both (1) normal to the largest planar faces and (2) co-directional with the axes of symmetry of the largest axisymmetric GCDs. It then creates turning axes that coincide with the axes of symmetry of the largest (greatest surface area) GCDs with convex surfaces. For Casting and Forging, all automatically-created turning axis are parallel to one another.

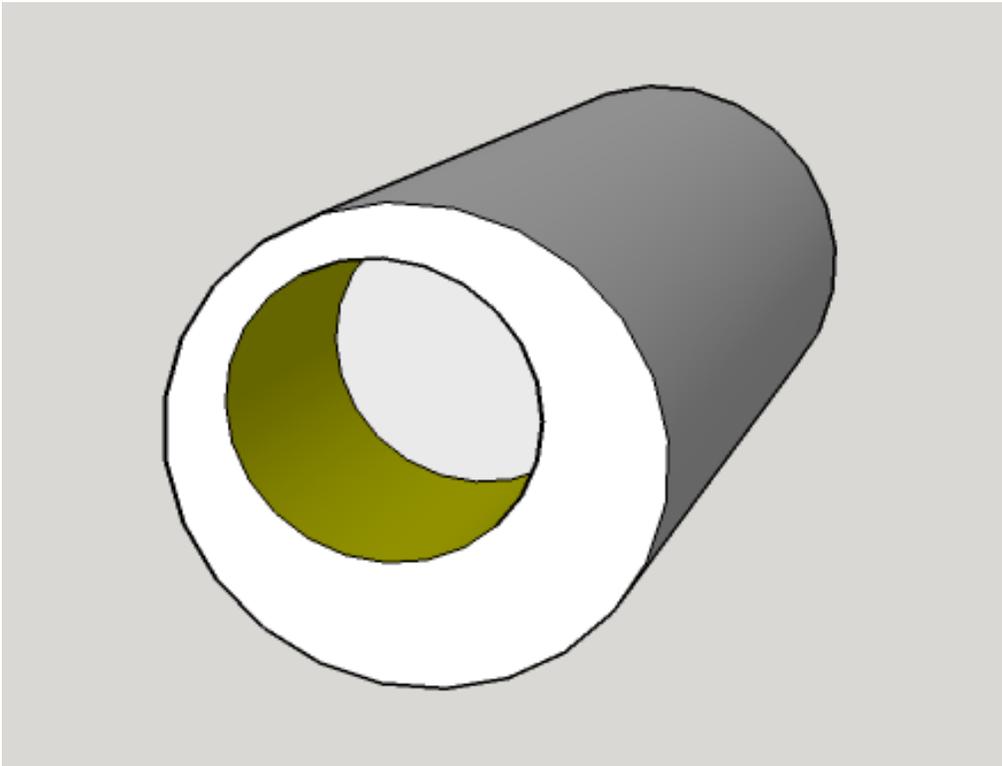
The default maximum number of system-created turning axis pairs is determined by the site variable **maxNumTurningAxes**, which is set to 1 in aPriori starting point VPEs. You can override this number for a specific part, if your part requires two or more different (but parallel) turning orientations (as with camshafts, for example). You can also override this maximum to specify that a part should not be turned. See [Limiting Turning Axes](#).

In addition, for the casting, forging, and 2-model process groups (as well as for stock machining—see above), you can specify additional, user-defined turning axes. Do this, for example, if your part requires a turning axis that is not parallel to the system defined turning axes. See [User-defined Turning Axes](#).

User-defined Turning Axes

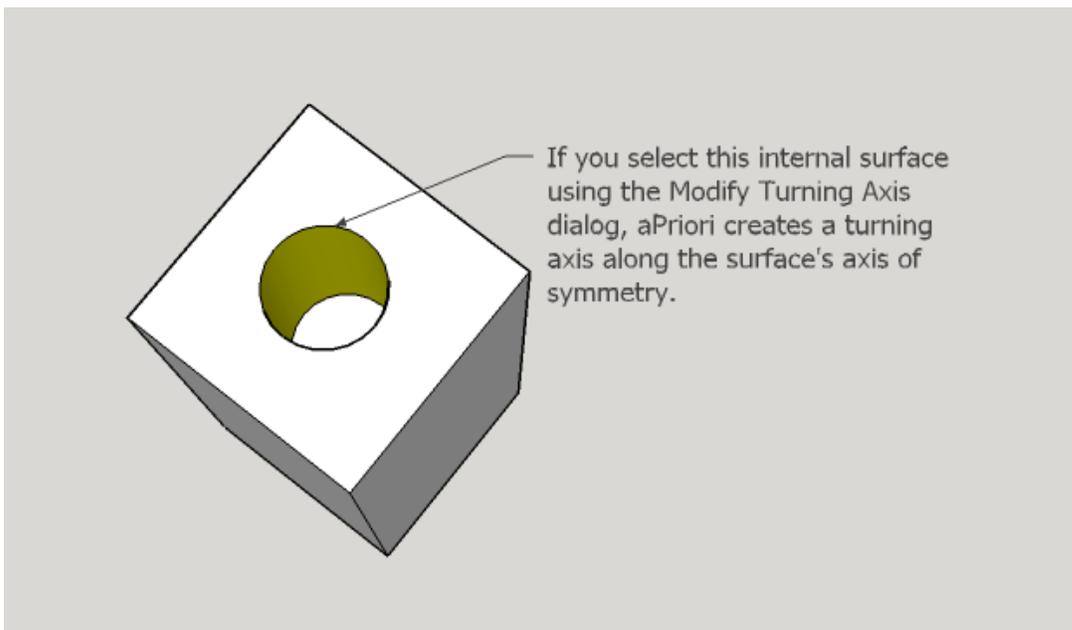
Some parts require turning axes that are not automatically created by aPriori (see [System-created Turning Axes](#)). Consider, for example, the following:

Stock machining, off-center, turnable feature: system-created turning axes for stock machining are always along the stock center line. (The allowable distance from the part center of mass is determined by the site variable **maxTurningAxisEccentricity**, 0.05 in aPriori starting point VPEs.) If your part requires off-center turning axes, specify user-defined turning axes.



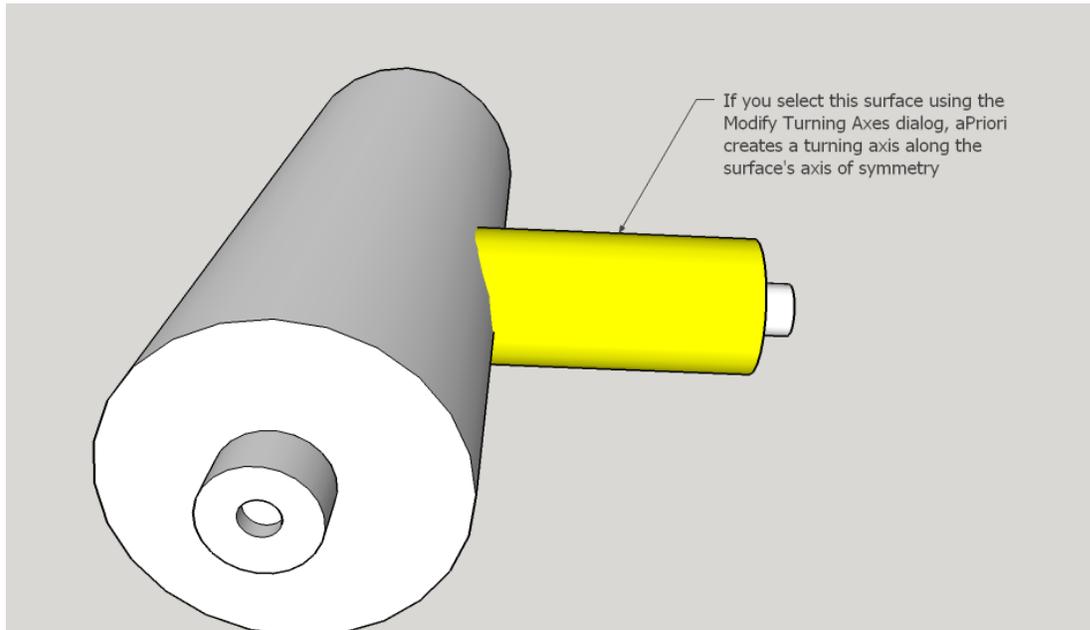
With stock machining, off-center features (such as the surface in yellow) do not have associated system-created turning axes. Users can define turning axes any axisymmetric GCD with the Modify Turning Axes dialog.

Stock machining, turnable feature in square or rectangular stock: there are no system-created turning axes for square or rectangular stock. If your part uses square or rectangular stock and has turnable features, specify user-defined turning axes.



With stock machining, there are no system-created turning axes for square or rectangular stock. Users can define turning axes for any axisymmetric GCD with the Modify Turning Axes dialog.

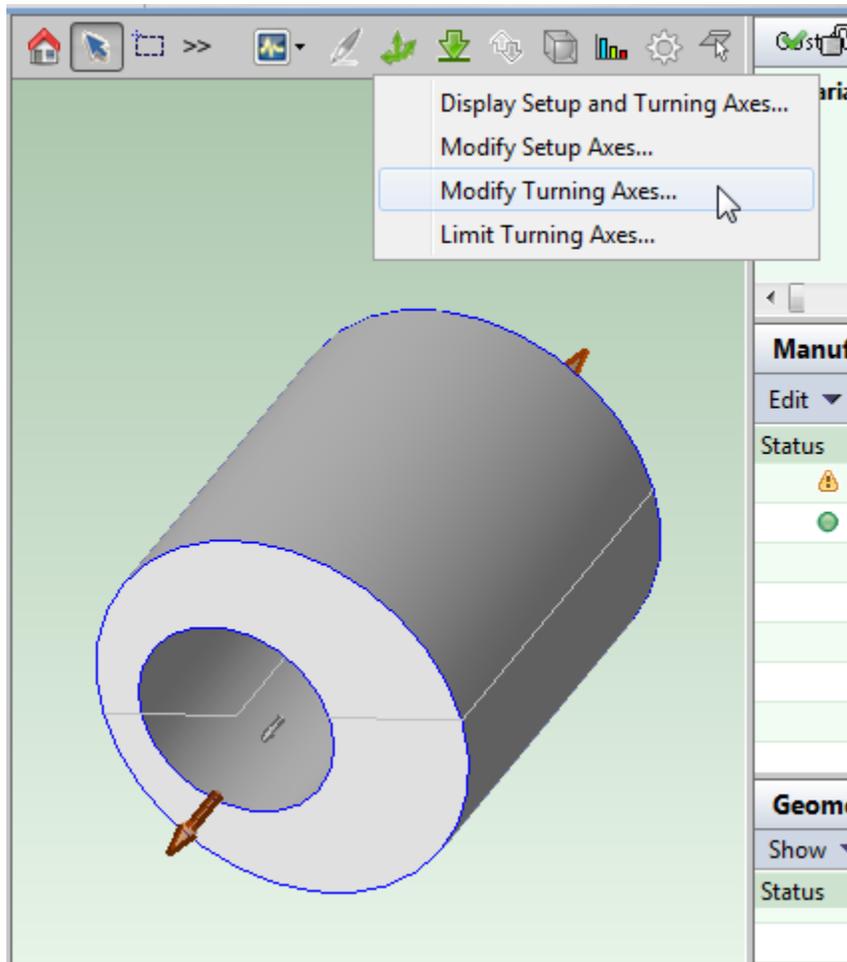
Non-parallel turnable features: system-created turning axes for a given part are all parallel to one another. If your part has non-parallel, turnable features, specify user-defined turning axes.



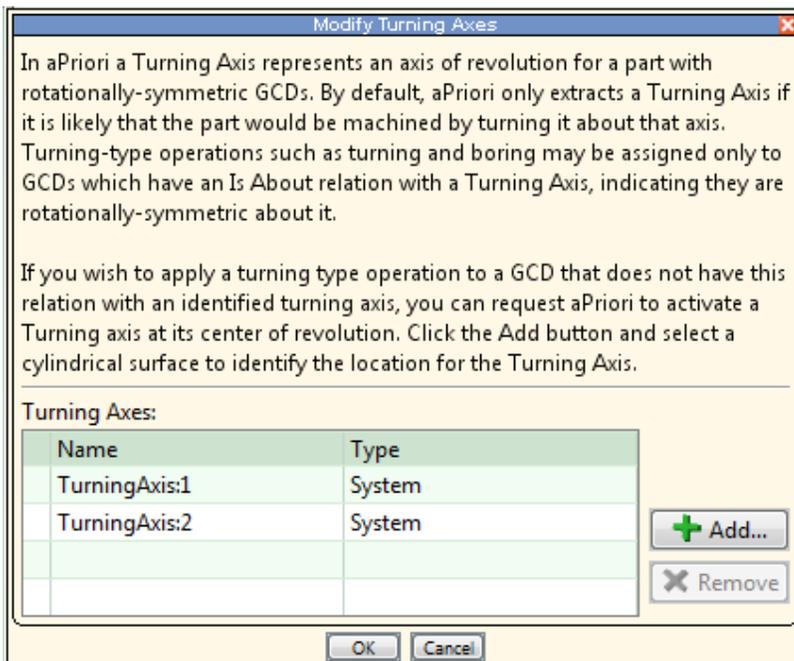
System-created turning axes are all parallel to one another. For features that require a turning axis that is not parallel to the system-created turning axes, users can create a turning axis with the Modify Turning Axes dialog, provided the current process group is Casting, Forging, 2-Model, or Stock Machining.

Follow these steps to specify user-defined turning axis pairs:

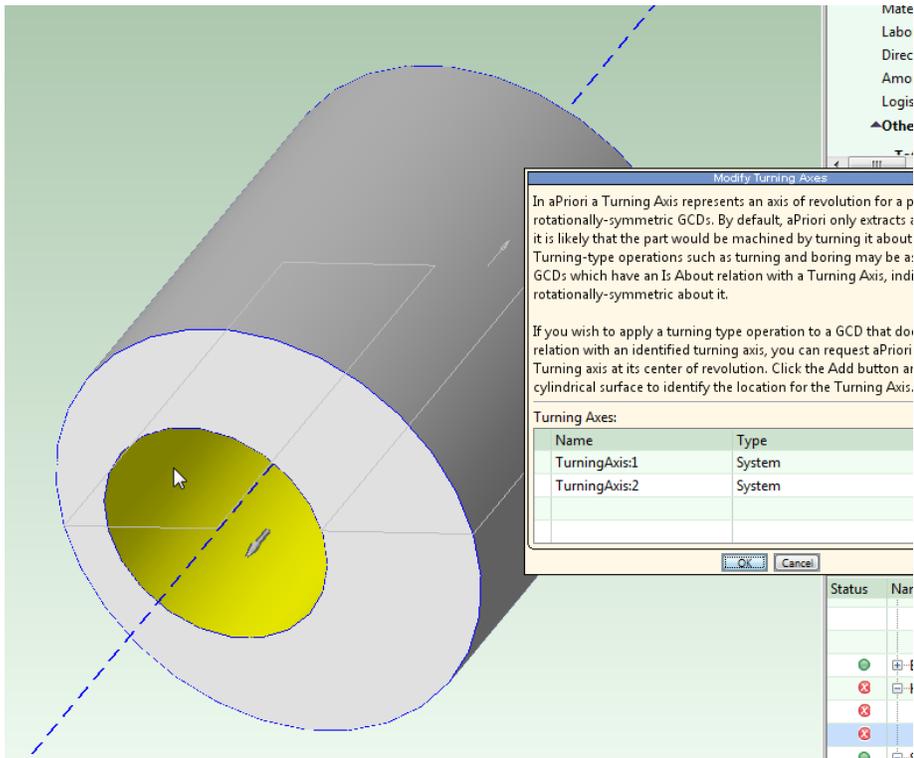
- 1 In the Viewer toolbar, Click the setup axis tool, , and select **Modify Turning Axes...** from the popup menu.



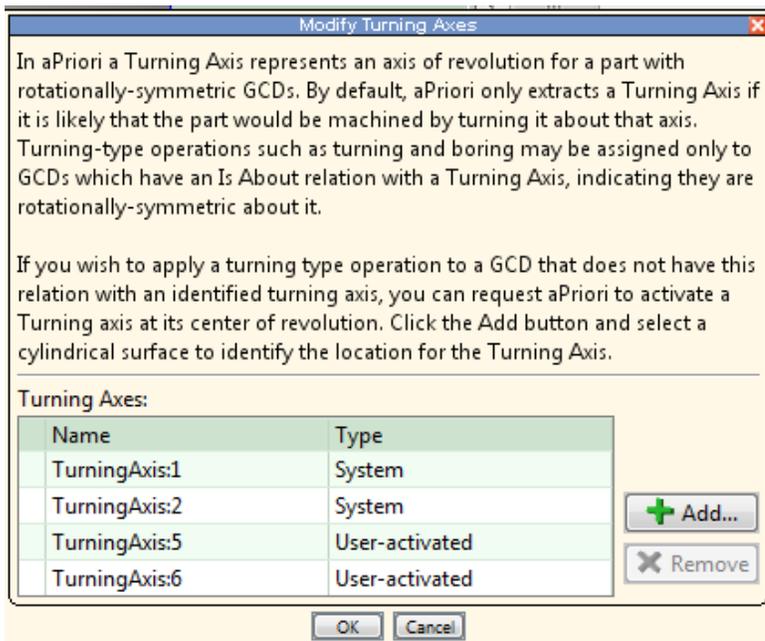
The Modify Turning Axes dialog appears.



- 2 Click the **Add...** button. When you hover over an axisymmetric GCD, aPriori highlights it in yellow, and displays a blue, dashed centerline.
- 3 Click the GCD to be turned.



aPriori creates a pair of user-defined turning axes along the axis of symmetry of the specified GCD.



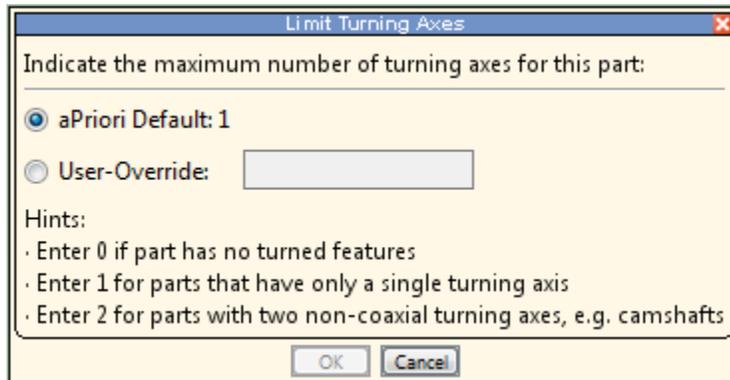
- 4 Click **OK**.

You can remove a user-defined turning axis pair by selecting an axis in the pair and clicking **Remove**.

Limiting Turning Axes

Follow these steps to specify the number of system-created turning axis pairs for the current part:

- 1 In the Viewer toolbar, Click the setup axis tool, , and select **Limit Turning Axes...** from the popup menu. The Limit Turning Axes dialog appears.



- 2 Click the User override radio button, and enter one the following:
 - o 0: if the part should be turned
 - o 1: if the part has a single turning axis pair
 - o 2 or more if the part has 2 or more parallel, non-coaxial turning axis pairs.
- 3 Click **OK**.

Displaying Setups, Associated Operations, and GCDs

You can understand which setups are active and which operations are performed from that setup to machine specific GCDs, by using the Manufacturing Process Pane, shown below.

Manufacturing Process		
Edit ▾ View ▾		Primary Process Group: Stock Machining
		Material: Steel, HR, AISI 1010
Status	Process Step	VPE
	POCKET_DRAFT-AFTER-ROUND	
	Stock Machining	aPriori USA
	Nonround Stock	aPriori USA
	Stock Prep	aPriori USA
	Machining	aPriori USA
	3 Axis Mill [2]	aPriori USA
	Setup (SetupAxis:1)	aPriori USA
	Setup:2 (SetupAxis:2)	aPriori USA
	Finishing	
	Contouring	
	Facing	
	PlanarFace:2	aPriori USA
	PlanarFace:7	aPriori USA
	Indirect Filleting	
	Bulk Milling	aPriori USA

Each process will have one or more part Setup operations underneath it, with the name of the specific setup or turning axis GCD following in parentheses. You can perform the following actions to better understand what machining is performed from each setup:

- If you click on a Setup node, the aPriori Viewer window will display the associated axis in yellow, so you can understand the direction of the axis and therefore the orientation of the part in that setup.
- If you right-click on a Setup node and select Highlight Associated GCDs, the aPriori Viewer window will display all GCDs that are machined from that setup, in yellow, as well as the setup axis itself.
- If you expand the Setup node, you will see nodes under it representing different types of machining operations (e.g., Finishing, which in turn has nodes representing different types of surface finishing operations such as facing, side-milling, or contouring). Under those specific operation nodes will appear the specific GCDs machined by each operation. In the example above, PlanarFace:2 is Faced, on the second part setup which is in the direction of SetupAxis:2.

To see both active and inactive setup axes, click on the Setup Axis tool in the Viewer tool bar, then select **Display Setup and Turning Axes...** The resulting window allows you to independently display both active and inactive (candidate) setup axes.

Setup Axes and Operation Feasibility

As part of the process of costing a part for a particular process routing, aPriori traverses the part's GCD hierarchy and performs operation assignment (that is, it assigns an operation sequence to each GCD). In the course of performing operation assignment, aPriori is often faced with a choice between alternative operations. In such situations, aPriori uses heuristics to make some inferences about the following costs of each operation for the current GCD:

- Required cutting time

- Setup requirements (how the part must be oriented on the machine in order to make the current GCD accessible to this operation; whether the operation requires an orientation not required by any other operation)

For example, in choosing between Facing and Side Milling for a particular feature of a particular part, aPriori might take into account both the following:

- Facing typically requires less cutting time, but in this case (let us suppose) has the disadvantage of requiring an extra setup.
- Side Milling typically requires more cutting time, but in this case (let us suppose) has the advantage of being able to use a setup already required by another operation on the current part (thus saving the time required to re-orient the part).

When aPriori makes such choices, it does not fully cost each possible operation sequence and compare the results (as it does for each process routing, once it has performed operation assignment). Instead, it attempts to choose the best operation sequence by doing both the following:

- aPriori considers candidate operations in order, from typically faster operations (in terms of cutting time) to typically slower ones. So, for example, when Facing and Side Milling are considered as alternatives, Facing is considered before Side Milling (since, when feasible, Facing generally requires less cutting time for a given GCD than Side Milling). Similarly Side Milling is considered before Contouring.
- When aPriori considers an operation for a given GCD, the operation's feasibility module uses various heuristics to judge whether the costs associated with the operation's setup requirements are likely to outweigh the benefits of shorter cutting time. If the setup costs are likely to outweigh the cutting time benefits, aPriori considers the operation infeasible.

For example, facing a planar face on a 3-Axis Mill is infeasible if the operation requires a special setup to accommodate it, unless the planar face has a sufficiently large surface area (as a fraction of the part's total surface area).

This section describes the feasibility rules that aPriori uses in order to determine when setup requirements render an operation infeasible.

You can influence aPriori's feasibility determinations in a number of ways, including by doing one or more of the following:

- Override aPriori's choice of *principal* setups--see [Overriding Principal Setup Axes](#).
- Add one or more user-specified *activated* setups—see [Activating Setup Axes](#).
- Adjust the cost model variable **fractionalAreaSetupTrigger**—see facing and side milling under **Planar Face** in [3-Axis Mill](#).
- Adjust the routings by explicitly user-including an operation—see [Modifying Machining Operation Assignments](#).

This section contains the information you need for a detailed understanding of how these user actions affect operation assignment.

The section has the following subsections:

- [GCD Accessibility and Tool Orientations](#)
- [GCD Accessibility and Setup Axes](#)

- Operation Assignment
- 3-Axis Mill
- 4-Axis Mill
- 5-Axis Mill
- 2-AxisLathe
- 3-AxisLathe
- Mill Turn

GCD Accessibility and Tool Orientations

When aPriori analyzes a part's geometry, it analyzes the nature of each GCD's accessibility from each direction from which a tool might usefully approach, and represents the results as **Is Accessible From** relations. (See GCD Relations in the Geometric Cost Drivers pane.) The following types of accessibility are possible:

- **Parallel:** a tool oriented parallel to the GCD could approach from the specified direction without obstruction. In this case the tool orientation is parallel (unobstructed) to the GCD.
- **Parallel obstructed:** a tool oriented parallel to the GCD could approach from the specified direction, but would be somewhat obstructed. In this case some tools may be able to access the GCD despite the obstruction, or the GCD may be accessible using combination of different tool orientations (see [Multiple Approach Surface Finishing](#)).
- **Normal:** a tool oriented normal to the GCD could approach from the specified direction without obstruction. In this case the tool orientation is normal (unobstructed) to the GCD.
- **Normal obstructed:** a tool oriented normal to the GCD could approach from the specified direction, but would be somewhat obstructed. In this case some tools may be able to access the GCD despite the obstruction, or the GCD may be accessible using combination of different tool orientations (see [Multiple Approach Surface Finishing](#)).
- **Oblique:** a tool oriented oblique to the GCD could approach from the specified direction without obstruction. In this case the tool orientation is oblique (unobstructed) to the GCD.
- **Oblique obstructed:** a tool oriented oblique to the GCD could approach from the specified direction, but would be somewhat obstructed. In this case some tools may be able to access the GCD despite the obstruction.

A GCD is at least partially accessible from the direction specified by a tool orientation if there exists an **Is Accessible From** relation whose value for **first** is the GCD and whose value for **second** is the tool orientation (setup axis). The type of accessibility (parallel, parallel obstructed, normal, etc.) is specified by the **Direction Type** attribute of the **Is Accessible From** relation.

Different operations require different types of accessibility. For example, a facing operation on a planar face requires that there is a tool orientation that is normal (unobstructed) to the planar face (but see also [Multiple Approach Surface Finishing](#)).

The table below shows the general requirements for some basic types of machining operations:

Tool orientation/GCD relationship	Facing	Side Milling	Contouring	Hole Making
Planar Face	Normal (unobstructed)	Parallel (unobstructed)	Oblique (unobstructed)	
Curved Wall		Parallel (unobstructed)	Oblique (unobstructed)	
Curved Surface			Oblique (unobstructed)	
Hole				Parallel (unobstructed) or Parallel obstructed

Note that parallel, normal, and oblique are defined as follows for different GCD types:

- Parallel
 - Planar face: a setup axis is parallel to a planar face if some line segment in the planar face runs along the direction specified by the setup axis.
 - Curved wall: a setup axis is parallel to a curved wall if the *rules* of the wall run along the direction specified by the setup axis. (A curved wall can be thought of as described by the motion of a line segment, or rule, translated--and not rotated--through space along a smooth curve.)
 - Ruled curved surface: a setup axis is parallel to a ruled curved surface if the average direction of the rules is the same as the direction specified by the setup axis. (A ruled curved surface can be thought of as generated by the motion of a line segment, or rule, translated and rotated through space.)
 - Unruled curved surface: a setup axis is parallel to an unruled curved surface if the average direction of normals to the surface is the same as the direction specified by the setup axis.
 - Axisymmetric GCD: a setup axis is parallel to an axisymmetric GCD if its axis of symmetry runs along the same direction as that specified by the setup axis.
- Normal
 - Planar face: a setup axis is normal to a planar face if it is normal to every line segment in the planar face.
 - Curved wall: a setup axis is normal to a curved wall if it is normal to the rules of the curved wall.
 - Ruled curved surface: a setup axis is normal to a ruled curved surface if it is normal to the average direction of the rules of the curved surface.
 - Unruled curved surface: a setup axis is normal to an unruled curved surface if it is normal to the average direction of normals to the surface.

- Axisymmetric GCD: a setup axis is normal to an axisymmetric GCD if it is normal to the GCD's axis of symmetry.
- Oblique: s setup axis is oblique to a GCD if it is neither parallel nor normal to it.

GCD Accessibility and Setup Axes

The following sections detail the conditions under which a setup is appropriate for various types of operations on various types of milling and turning machines. These sections say that a setup axis “*would (if used) render accessible*” a GCD for an operation” as shorthand for the following:

- Were the part to be oriented as specified by the setup axis (see [Part Orientations](#)), the GCD would have the required type of accessibility from a direction from which the tool can approach (see [GCD Accessibility and Tool Orientations](#)).

This section has the following subsections:

- [Non-rotational Setup Axes for 3- and 4-Axis Mill](#)
- [Rotational Setup Axes for 4-Axis Mill](#)
- [Setup Axes for 5-Axis Mill](#)
- [Turning Axes for 3-Axis Lathe](#)

Non-rotational Setup Axes for 3- and 4-Axis Mill

Since a non-rotational setup axis points in the direction from which the tool approaches (when the part is oriented as specified by the setup axis), a non-rotational setup axis generally would (if used) render a GCD accessible for an operation when the following holds:

- The GCD has the required accessibility (see [GCD Accessibility and Tool Orientations](#)) from the direction specified by the setup axis.

For example, a non-rotational setup axis would (if used) render a planar face accessible to a facing operation if the setup axis is normal (unobstructed) to the planar face.

The table below (which is essentially the same as the table in [GCD Accessibility and Tool Orientations](#)) shows when a non-rotational setup axis generally would (if used) make a GCD accessible for some basic types of machining operations on a 3- or 4-axis mill:

Setup axis/GCD relationship	Facing	Side Milling	Contouring	Hole Making
Planar Face	Normal (unobstructed)	Parallel (unobstructed)	Oblique (unobstructed)	
Curved Wall		Parallel (unobstructed)	Oblique (unobstructed)	
Curved Surface			Oblique (unobstructed)	

Hole				Parallel (unobstructed) or Parallel obstructed
------	--	--	--	--

See also [Multiple Approach Surface Finishing](#).

Note also that a 4-Axis mill that supports machining while its rotational axis is turning can face a curved wall provided that the curved wall is convex.

Rotational Setup Axes for 4-Axis Mill

On a 4-axis mill, the spindle is perpendicular to the axis of rotation, so a rotational setup axis is perpendicular to the direction from which the tool approaches. This means that a rotational setup axis on a 4-axis mill generally would (if used) render a GCD accessible to an operation if the following holds:

- The GCD has the required accessibility (see [GCD Accessibility and Tool Orientations](#)) from some tool orientation that is perpendicular to the setup axis.

For example, a rotational setup axis on a 4-axis mill would (if used) render a planar face accessible to a facing operation if the setup axis is perpendicular to some tool orientation that is normal (unobstructed) to the planar face.

The table below indicates when a rotational setup axis generally would (if used) make a GCD accessible for some basic types of machining operations on a 4-axis mill:

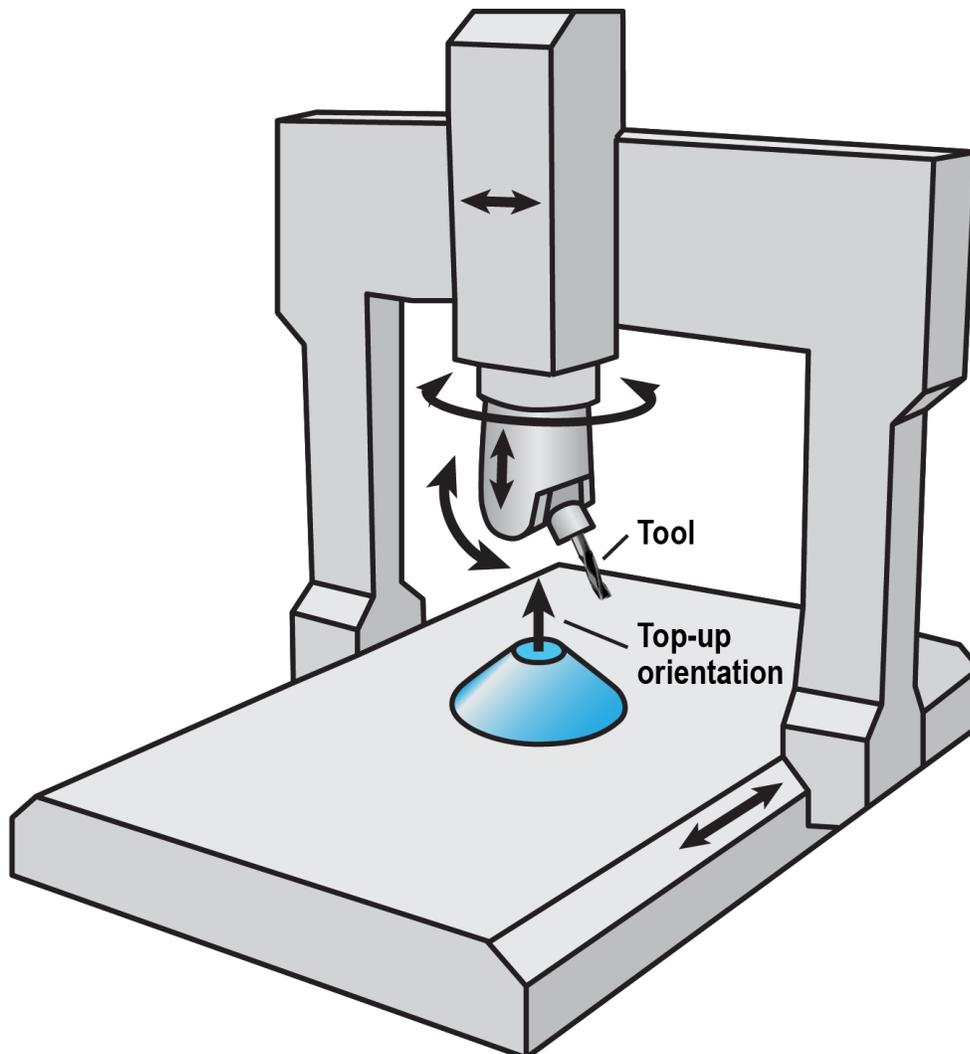
Setup axis/GCD relationship	Facing	Side Milling	Contouring	Hole Making
Planar Face	Perpendicular to a tool orientation that is normal (unobstructed)	Perpendicular to a tool orientation that is parallel (unobstructed)	Perpendicular to a tool orientation that is oblique (unobstructed)	
Curved Wall		Perpendicular to a tool orientation that is parallel (unobstructed)	Perpendicular to a tool orientation that is oblique (unobstructed)	
Curved Surface			Perpendicular to a tool orientation that is oblique (unobstructed)	
Hole				Perpendicular to a tool orientation that is parallel (unobstructed)

				or Parallel obstructed
--	--	--	--	------------------------

See also Multiple Approach Surface Finishing.

Setup Axes for 5-Axis Mill

Like a 4-axis mill, a 5-axis mill can rotate the part. A 5-axis mill can also tilt the part or the spindle up to a maximum tilt angle, which is specified by the machine attribute `maxTiltAngle`.



On the 5-axis mill machines currently supported by aPriori starting point VPEs, the spindle is parallel to the axis of rotation, when the machine table or spindle is not tilted. So a setup axis on a 5-axis mill generally would (if used) render a GCD accessible to an operation if the following holds:

- The GCD has the required accessibility from some tool orientation that is within **maxTiltAngle** of the setup axis.

For example, a setup axis on a 5-axis mill would (if used) render a planar face accessible to facing if the setup axis is within **maxTiltAngle** of some tool orientation that is normal (unobstructed) to the planar face. The table below shows when a rotational setup axis generally would (if used) make a GCD accessible for some basic types of machining operations on a 5-axis mill:

Setup axis/GCD relationship	Facing	Side Milling	Contouring	Hole Making
Planar Face	Within maxTiltAngle of a tool orientation that is normal (unobstructed)	Within maxTiltAngle of a tool orientation that is parallel (unobstructed)	Within maxTiltAngle of a tool orientation that is oblique (unobstructed)	
Curved Wall		Within maxTiltAngle of a tool orientation that is parallel (unobstructed)	Within maxTiltAngle of a tool orientation that is oblique (unobstructed)	
Curved Surface			Within maxTiltAngle of a tool orientation that is oblique (unobstructed)	
Hole				Within maxTiltAngle of a tool orientation that is parallel (unobstructed) or Parallel obstructed

See also [Multiple Approach Surface Finishing](#).

Note also that Ruled Curved Surfaces can be Side Milled by aPriori's supported type of 5-Axis Mill provided that the maximum inclination of the ruled surface does not exceed the maximum tilt angle.

Turning Axes for 3-Axis Lathe

On a 3-axis lathe, the spindle of the live tooling (mill cutters that can be mounted to the machine and spun by independent motors) can be either perpendicular or parallel to the

machine's turning axis. This means that a turning axis on a 3-axis lathe generally would (if used) render a GCD accessible to an operation if the following holds:

- The GCD has the required accessibility from some tool orientation that is perpendicular or parallel to the turning axis.

For example, a turning axis on a 3-axis lathe would (if used) render a planar face accessible to a facing operation if the turning axis is perpendicular to some tool orientation that is normal (unobstructed) to the planar face. The table below indicates when a turning axis generally would (if used) make a GCD accessible for some basic types of machining operations on a 3-axis lathe:

Turning axis/GCD relationship	Facing	Side Milling	Contouring	Hole Making
Planar Face	Perpendicular or parallel to a tool orientation that is normal (unobstructed)	Perpendicular or parallel to a tool orientation that is parallel (unobstructed)	Perpendicular or parallel to a tool orientation that is oblique (unobstructed)	
Curved Wall		Perpendicular or parallel to a tool orientation that is parallel (unobstructed)	Perpendicular or parallel to a tool orientation that is oblique (unobstructed)	
Curved Surface			Perpendicular or parallel to a tool orientation that is oblique (unobstructed)	
Hole				Perpendicular or parallel to a tool orientation that is parallel (unobstructed) or Parallel obstructed

Operation Assignment for Machining

As described in [Setup Axes and Operation Feasibility](#), when aPuri costs a part, it traverses the part's GCD hierarchy and performs operation assignment. In order to assign an operation to a GCD, aPuri must identify a setup axis that makes the GCD accessible for the operation (on the machine associated with the operation's intended

parent process). The sections [GCD Accessibility and Tool Orientations](#) and [GCD Accessibility and Setup Axes](#) describe how aPriori determines whether a given setup axis makes a GCD accessible for an operation.

Each operation's feasibility module contains rules that determine which setup axes are considered as candidates and the order in which they are considered. If none of the setup axes under consideration makes the GCD accessible, aPriori considers the operation infeasible. The following sections describe these rules for milling operations on surfaces and simple holes:

- 3-Axis Mill
- 4-Axis Mill
- 5-Axis Mill
- 2-AxisLathe
- 3-AxisLathe
- Mill Turn

In general, the feasibility modules for milling processes use roughly the following strategy:

- 1 For rotational machines (4- and 5-axis mills), check the rotational axes to see if one makes the GCD accessible. If one does, assign the operation (assuming it is feasible in non-setup-related respects). If not, continue with the steps below.
- 2 For both rotational and non-rotational machines, check the principal and user-activated setup axes to see if one makes the GCD accessible. If one does, assign the operation (assuming it is feasible in non-setup-related respects). Otherwise continue with the steps below.
- 3 For holes and axigrooves, check all currently activated setup axes to see if one makes the GCD accessible. If one does, assign the operation (if it is feasible in non-setup-related respects). Otherwise, activate a heretofore inactive setup axis that would (if used) render the GCD accessible, and assign the operation (if it is otherwise feasible).
- 4 For surfaces, come back later to the feasibility check for this GCD and operation. For now, move on to other operations for this GCD and then to operation assignment for all the other GCDs (to see if one of them activates a relevant setup axis). Then, if the GCD remains unassigned, return to the feasibility check for this GCD and operation.
- 5 Check all currently activated setup axes to see if one makes the GCD accessible. If one does, assign the operation (assuming it is otherwise feasible). Otherwise, consider the operation infeasible.

In certain special cases for surfaces, instead of considering the operation infeasible, aPriori activates a heretofore un-activated setup axis that would (if used) render the surface accessible and assigns the operation.

In addition, aPriori sometimes executes the last two steps one extra time. If that fails to find a suitable setup axis, the operation is considered infeasible.

Note that this section describes the strategy used during fully automated, not semi-automated, machining—see [Semi-automated Costing](#).

To help implement this strategy, aPriori traverses the GCD hierarchy 3 or 4 times:

- The first time, it skips axisymmetric GCDs such as simple holes, and generally considers principal and user-activated setups.
- In the second pass it considers only axisymmetric GCDs, and principle and activated setups; it activates a setup to accommodate the axisymmetric GCD if necessary.
- In the third pass aPriori considers surfaces again, and considers activated setups. In special cases, it activates a setup to accommodate the GCD if necessary.
- In some cases, aPriori makes a fourth pass to consider surfaces yet again and check any setups activated in the third pass.

aPriori ensures that in-use, feasible setup axes are always preferred to feasible setup axes that are not yet in use by any operation. It does this by doing both the following:

- The strategy above always prefers activated to un-activated setup axes. Other than the initially-activated setup axes, only in-use axes become activated.
- aPriori orders the setup axes by axis key (an ID number for each axis). Among initially-activated setup axes (the principle and user-activated ones), aPriori always picks the earliest of two setup axes that are equally qualified for an operation.

All other things being equal, the feasibility rules generally favor setup axes that provide better access to corners (allowing a larger diameter tool). Of course, feasibility rules also impose various other requirements, such as an acceptable ratio of tool length to tool diameter. See [Operation Routing and Feasibility for Machining](#).

3-Axis Mill

This section covers setup requirements for operations on the following GCD types:

- Planar Face
- Curved Wall
- Curved Surface
- Simple Hole

When operations are alternatives of each other, the operations are listed in the order in which they are considered by aPriori (the order in which they are listed in the template).

Note that, as described below, 3-Axis Mill feasibility rules take into account whether the current GCD is part of a *parallel surface chain* (PSC). See [Parallel Surface Chain](#).

Parallel Surface Chain

A parallel surface chain (PSC) consists of a closed loop of planar faces and curved walls that are all parallel to each other in the following sense:

- The rules of a PSC's curved walls all run in the same direction.
- Each planar face of a PSC contains lines that are co-directional with rules of the PSC's curved walls.

See also [PSCs and Perimeters](#).

It is often possible (and desirable) for all the surfaces of a PSC to be side milled using a single setup. Therefore, aPriori takes PSCs into account when activating setup axes and evaluating the feasibility of operations on planar faces and curved walls:

- For a curved wall that is part of a PSC, if no active setup axis makes it accessible to side milling, aPriori activates a setup axis that makes the surface accessible to side milling, assuming side milling is otherwise feasible for the surface.
- In passes 1-3 (see [Operation Assignment for Machining](#)), Rounding and Filleting are infeasible for a curved wall that is part of a PSC.
- For a planar face that is part of a PSC, if no active setup axis makes all the PSC's surfaces accessible to side milling, aPriori activates a setup axis that makes all the surfaces of the PSC accessible to side milling, assuming side milling is otherwise feasible for the surface.
- In passes 1-3 (see [Operation Assignment for Machining](#)), Facing is infeasible for a planar face that is part of a PSC, provided that it is accessible to side milling from some candidate setup axis and has no sharp corners that are inaccessible from that setup axis.

Planar Face

- Facing: setup axis must provide access to the GCD from a direction normal to the GCD.

If the operation is part of a multi-approach operation sequence (which is considered only after single-approach finishing has been found infeasible--see [Multiple Approach Surface Finishing](#)), use an activated setup axis that provides obstructed access to at least 2.5% of the GCD, if one exists.

If the operation is not part of a multi-approach operation sequence and if the process setup option **Machining Automation Level** is set to **Semi Automated**, check the following setup axes in this order:

- Principal
- User-activated

If none would (if used) render this GCD fully accessible, the operation is infeasible.

If the operation is not part of a multi-approach operation sequence and the process setup option **Machining Automation Level** is set to **Fully Automated**, and the planar face *is not* part of a PSC (see [Parallel Surface Chain](#)), check the following setup axes in this order:

- Principal
- User-activated

If none would (if used) render this GCD fully accessible, come back later to the feasibility check for this GCD and operation, if necessary. For now, move on to other operations (except multi-approach operations) for this GCD and then to operation assignment for all the other GCDs. Then, if the GCD remains unassigned, check the following setup axes for this GCD:

- All activated (non-principle, non-user-activated) setup axes

If no activated setup axis would (if used) render the GCD fully accessible, check the following condition:

- The GCD's surface area is a sufficiently large fraction of the total surface area of the part (as specified by the cost model variable **fractionalAreaSetupTrigger**)

If the condition is met, activate a setup axis that would (if used) render the GCD fully accessible, if one exists.

Otherwise, use an activated setup axis that provides access to at least 99% of the surface (in this case, aPiori assumes the use of a tool that can slide under a small undercut, such as a reduced shank mill).

Otherwise the operation is infeasible.

If the process setup option **Machining Automation Level** is set to **Fully Automated**, and the planar face *is* part of a PSC, come back later to the feasibility check for this GCD and operation, if necessary. For now, move on to other operations for this GCD and then to operation assignment for all the other GCDs. Then, if the GCD remains unassigned, check all activated setup axes.

If no activated setup axis would (if used) render the GCD fully accessible, check the following condition:

- The GCD's surface area is a sufficiently large fraction of the total surface area of the part (as specified by the cost model variable **fractionalAreaSetupTrigger**)

If the condition is met, activate a setup axis that would (if used) render the GCD fully accessible, if one exists.

Otherwise the operation is infeasible.

- Side milling: setup axis and GCD must be parallel.

If the operation is part of a multi-approach operation sequence (which is considered only after single-approach finishing has been found infeasible--see [Multiple Approach Surface Finishing](#)), use an activated setup axis that provides obstructed access with access to at least 2.5% of the surface, if one exists.

Otherwise, if the process setup option **Machining Automation Level** is set to **Semi Automated**, check the following setup axes in this order:

- Principal
- User-activated

If none would (if used) render this GCD fully accessible, the operation is infeasible.

If the process setup option **Machining Automation Level** is set to **Fully Automated**, and the planar face *is not* on a PSC (see [Parallel Surface Chain](#)), check the following setup axes in this order:

- Principal
- User-activated

If none would (if used) render this GCD fully accessible, come back later to the feasibility check for this GCD and operation, if necessary. For now, move on to other operations for this GCD and then to operation assignment for all the other GCDs. Then, if the GCD remains unassigned, check the following setup axes for this GCD:

- All activated (non-principle, non-user-activated) setup axes

If no activated setup axis would (if used) render the GCD fully accessible, check the following condition:

- The GCD is a wall of a complex hole whose contours lie in parallel planes and whose walls are normal to these planes.

If the condition is met, activate a setup axis that would (if used) render the GCD fully accessible, if one exists.

If the condition is not met, check the following condition:

- The GCD's surface area is a sufficiently large fraction of the total surface area of the part (as specified by the cost model variable **fractionalAreaSetupTrigger**)

If the condition is met, activate a setup axis that would (if used) render the GCD fully accessible, if one exists.

Otherwise the operation is infeasible.

If the process setup option **Machining Automation Level** is set to **Fully Automated**, and the planar face *is* on a PSC, check the following setup axes to see if the render fully accessible all surfaces on the PSC:

- Principal
- User-activated

If none would (if used) render all the PSC's surfaces fully accessible, come back later to the feasibility check for this GCD and operation, if necessary. For now, move on to other operations for this GCD and then to operation assignment for all the other GCDs. Then, if the GCD remains unassigned, check the following setup axes for PSC:

- All activated (non-principle, non-user-activated) setup axes

If no activated setup axis would (if used) render the PSC's surfaces fully accessible, activate a setup axis that would (if used) render all the PSC's surfaces accessible to side milling.

If no setup axis would render all the PSC's surfaces fully accessible, check all activated setup axes to see if one would make the current planar face accessible to side milling. If there is none, check the following condition:

- The GCD's surface area is a sufficiently large fraction of the total surface area of the part (as specified by the cost model variable **fractionalAreaSetupTrigger**)

If the condition is met, activate a setup axis that would (if used) render the GCD fully accessible.

Otherwise the operation is infeasible.

- Contouring: setup axis must be oblique (unobstructed) to the GCD.

Check the following setup axes in this order:

- Principal
- User-activated

If none would (if used) render this GCD accessible, come back later to the feasibility check for this GCD and operation, if necessary. For now, move on to other operations for this GCD and then to operation assignment for all the other

GCDs. Then, if the GCD remains unassigned, check the following setup axes for this GCD:

- All activated (non-principle, non-user-activated) setup axes

If none would (if used) render this GCD accessible, the operation is infeasible.

- General mill finishing: This operation's setup requirements are always considered feasible.

Check for the existence of the following setup axes in this order:

- Principal perpendicular unobstructed
- User-activated perpendicular unobstructed
- Principal perpendicular obstructed
- User-activated perpendicular obstructed
- Principal parallel unobstructed
- User-activated parallel unobstructed
- Principal parallel obstructed
- User-activated parallel obstructed

If none exists, use the primary setup axis.

- Undercut milling: This operation is never auto-evaluated; it must be explicitly user-included. This operation's setup requirements are always considered feasible. The setup axis is preferred be parallel obstructed to the GCD.

Check the following setup axes in the following order:

- Principal
- User-activated

If none would (if used) render this GCD accessible, come back later to the feasibility check for this GCD and operation, if necessary. For now, move on to other operations for this GCD and then to operation assignment for all the other GCDs. Then, if the GCD remains unassigned, check the following setup axes for this GCD:

- All activated (non-principle, non-user-activated) setup axes

- Chamfer milling: This operation is never auto-evaluated; it must be explicitly user-included. The operation's setup requirements are always considered feasible.
- Mill grooving: This operation is never auto-evaluated; it must be explicitly user-included. The operation's setup requirements are always considered feasible.
- Rough milling: This operation's setup requirements are always considered feasible.

Check for the existence of the following setup axes in this order:

- Principal perpendicular unobstructed
- User-activated perpendicular unobstructed
- Principal perpendicular obstructed
- User-activated perpendicular obstructed
- Principal parallel unobstructed
- User-activated parallel unobstructed

- Principal parallel obstructed
- User-activated parallel obstructed

If none exists, use the primary setup axis.

Curved Wall

- Indirect filleting: setup axis must be normal to the GCD in such a way that this fillet can be produced by the corner of the tool.

If the curved wall is not part of a PSC (see [Parallel Surface Chain](#)), check the following setup axes in this order:

- Principal
- User-activated

If none would (if used) render this GCD accessible, come back later to the feasibility check for this GCD and operation, if necessary. For now, move on to other operations for this GCD and then to operation assignment for all the other GCDs. Then, if the GCD remains unassigned, check the following setup axes for this GCD:

- All activated (non-principle, non-user-activated) setup axes

If none would (if used) render this GCD accessible, the operation is infeasible.

If the curved wall *is* part of a PSC, come back later to the feasibility check for this GCD and operation, if necessary. For now, move on to other operations for this GCD and then to operation assignment for all the other GCDs. Then, if the GCD remains unassigned, check all activated setup axes. If none would (if used) render the GCD accessible, the operation is infeasible.

- Rounding: setup axis must be oblique (unobstructed) to the GCD.

If the curved wall *is not* part of a PSC (see [Parallel Surface Chain](#)), check the following setup axes in this order:

- Principal
- User-activated

If none would (if used) render this GCD accessible, come back later to the feasibility check for this GCD and operation, if necessary. For now, move on to other operations for this GCD and then to operation assignment for all the other GCDs. Then, if the GCD remains unassigned, check the following setup axes for this GCD:

- All activated (non-principle, non-user-activated) setup axes

If none would (if used) render this GCD accessible, the operation is infeasible.

If the curved wall *is* part of a PSC, come back later to the feasibility check for this GCD and operation, if necessary. For now, move on to other operations for this GCD and then to operation assignment for all the other GCDs. Then, if the GCD remains unassigned, check all activated setup axes. If none would (if used) render the GCD accessible, the operation is infeasible.

- Side milling: setup axis and GCD must be parallel (unobstructed).

If the operation is part of a multi-approach operation sequence (which is considered only after single-approach finishing has been found infeasible--see

Multiple Approach Surface Finishing), use an activated setup axis that provides obstructed access with access to at least 2.5% of the surface, if one exists.

Otherwise, if the curved wall *is not* part of a PSC (see [Parallel Surface Chain](#)), check the following setup axes:

- Principal

If neither would (if used) render this GCD fully accessible, come back later to the feasibility check for this GCD and operation, if necessary. For now, move on to other operations for this GCD and then to operation assignment for all the other GCDs. Then, if the GCD remains unassigned, check the following setup axes for this GCD:

- All activated (non-principle) setup axes

If no activated setup axis would (if used) render the GCD fully accessible, the operation is infeasible.

If the curved wall *is* on a PSC, check the following setup axes to see if the render fully accessible all surfaces on the PSC:

- Principal

If neither would (if used) render all the PSC's surfaces fully accessible, come back later to the feasibility check for this GCD and operation, if necessary. For now, move on to other operations for this GCD and then to operation assignment for all the other GCDs. Then, if the GCD remains unassigned, check the following setup axes for PSC:

- All activated (non-principle) setup axes

If no activated setup axis would (if used) render the PSC's surfaces fully accessible, activate a setup axis that would (if used) render all the PSC's surfaces fully accessible to side milling.

If no setup axis would render all the PSC's surfaces fully accessible, check all activated setup axes to see if one would make the current curved wall fully accessible to side milling. If there is none, the operation is infeasible.

- **Contouring:** setup axis must be oblique (unobstructed) to the GCD.

Check the following setup axes in this order:

- Principal
- User-activated

If none would (if used) render this GCD accessible, come back later to the feasibility check for this GCD and operation, if necessary. For now, move on to other operations for this GCD and then to operation assignment for all the other GCDs. Then, if the GCD remains unassigned, check the following setup axes for this GCD:

- All activated (non-principle, non-user-activated) setup axes

If none would (if used) render this GCD accessible, the operation is infeasible.

- **General mill finishing:** This operation's setup requirements are always considered feasible.

Check for the existence of the following setup axes in this order:

- Principal parallel unobstructed

- User-activated parallel unobstructed
- Principal parallel obstructed
- User-activated parallel obstructed
- Principal oblique unobstructed
- User-activated oblique unobstructed

If none exists, use the primary setup axis.

- Undercut milling: This operation is never auto-evaluated; it must be explicitly user-included. This operation's setup requirements are always considered feasible. The setup axis is preferred to be parallel obstructed to the GCD.

Check the following setup axes in the following order:

- Principal
- User-activated

If none would (if used) render this GCD accessible, come back later to the feasibility check for this GCD and operation, if necessary. For now, move on to other operations for this GCD and then to operation assignment for all the other GCDs. Then, if the GCD remains unassigned, check the following setup axes for this GCD:

- All activated (non-principle, non-user-activated) setup axes

- Rough milling: This operation's setup requirements are always considered feasible.

Check for the existence of the following setup axes in this order:

- Principal parallel unobstructed
- User-activated parallel unobstructed
- Principal parallel obstructed
- User-activated parallel obstructed
- Principal oblique unobstructed
- User-activated oblique unobstructed

If none exists, use the primary setup axis.

- Thread milling: setup axis must be parallel (unobstructed) to the GCD.

Check the following setup axes in this order:

- Principal
- User-activated

If none would (if used) render this GCD accessible, come back later to the feasibility check for this GCD and operation, if necessary. For now, move on to other operations for this GCD and then to operation assignment for all the other GCDs. Then, if the GCD remains unassigned, check the following setup axes for this GCD:

- All activated (non-principle, non-user-activated) setup axes

If none would (if used) render this GCD accessible, the operation is infeasible.

Curved Surface

- Indirect filleting: setup axis must be normal to the GCD in such a way that this fillet can be produced by the corner of the tool.

Check the following setup axes in this order:

- Principal
- User-activated

If none would (if used) render this GCD accessible, come back later to the feasibility check for this GCD and operation, if necessary. For now, move on to other operations for this GCD and then to operation assignment for all the other GCDs. Then, if the GCD remains unassigned, check the following setup axes for this GCD:

- All activated (non-principle, non-user-activated) setup axes

If none would (if used) render this GCD accessible, the operation is infeasible.

- Rounding: setup axis must be oblique (unobstructed) to the GCD.

Check the following setup axes in this order:

- Principal
- User-activated

If none would (if used) render this GCD accessible, come back later to the feasibility check for this GCD and operation, if necessary. For now, move on to other operations for this GCD and then to operation assignment for all the other GCDs. Then, if the GCD remains unassigned, check the following setup axes for this GCD:

- All activated (non-principle, non-user-activated) setup axes

If none would (if used) render this GCD accessible, the operation is infeasible.

- Contouring: setup axis must be oblique (unobstructed) to the GCD.

Check the following setup axes in this order:

- Principal
- User-activated

If none would (if used) render this GCD accessible, come back later to the feasibility check for this GCD and operation, if necessary. For now, move on to other operations for this GCD and then to operation assignment for all the other GCDs. Then, if the GCD remains unassigned, check the following setup axes for this GCD:

- All activated (non-principle, non-user-activated) setup axes

If none would (if used) render this GCD accessible, the operation is infeasible.

- General mill finishing: This operation's setup requirements are always considered feasible. The setup axis is preferred to be oblique (unobstructed) to the GCD.

Check the following setup axes in this order:

- Principal
- User-activated

If none would (if used) render this GCD accessible, come back later to the feasibility check for this GCD and operation, if necessary. For now, move on to

other operations for this GCD and then to operation assignment for all the other GCDs. Then, if the GCD remains unassigned, check the following setup axes for this GCD:

- All activated (non-principle, non-user-activated) setup axes

If none exists, use the primary setup axis.

- Rough milling: This operation's setup requirements are always considered feasible. The setup axis is preferred to be oblique (unobstructed) to the GCD.

Check the following setup axes in this order:

- Principal
- User-activated

If none would (if used) render this GCD accessible, come back later to the feasibility check for this GCD and operation, if necessary. For now, move on to other operations for this GCD and then to operation assignment for all the other GCDs. Then, if the GCD remains unassigned, check the following setup axes for this GCD:

- All activated (non-principle, non-user-activated) setup axes

If none exists, use the primary setup axis.

- Chamfer milling: This operation is never auto-evaluated; it must be explicitly user-included. The operation's setup requirements are considered feasible, if the GCD is a ruled curved surface (that is, if the surface could be generated by translational and rotational motion of a line segment through space).

Simple Hole

All 3-axis mill operations on simple holes employ a setup axis that is parallel (obstructed or nonobstructed) to the hole's axis of symmetry. Feasibility checks proceed as follows:

If the process setup option **Machining Automation Level** is set to **Semi Automated – principle setups only**, check the following setup axes in this order:

- Principal unobstructed
- User-activated unobstructed
- Principal obstructed
- User-activated obstructed

If none would (if used) render the GCD accessible, consider the operation infeasible.

If the process setup option **Machining Automation Level** is set to **Fully Automated**, check the following setup axes in this order:

- Principal unobstructed
- User-activated unobstructed
- All activated non-obstructed
- Un-activated unobstructed
- Principal obstructed
- User-activated obstructed
- All activated obstructed

- Un-activated obstructed

If an un-activated setup axis would (if used) render the GCD accessible, activate it (assuming the operation is otherwise feasible). If none of the above setup axes would (if used) render the GCD accessible, consider the operation infeasible.

Note that Step Drilling (manually selected) is also supported for multistep holes. The drill is step-shaped and creates an entire multistep hole in a single operation. Step Drilling is very productive when many multistep holes must be cut.

4-Axis Mill

This section covers setup requirements for operations on the following GCD types:

- Planar Face
- Curved Wall
- Curved Surface
- Simple Hole

When operations are alternatives of each other, the operations are listed in the order in which they are considered by aPriori (the order in which they are listed in the template).

Planar Face

- Facing: The setup axis must be one of the following:
 - Rotational parallel to the GCD and perpendicular to a tool orientation that is normal to the GCD
 - Nonrotational and normal to the GCD

If the operation is part of a multi-approach operation sequence (which is considered only after single-approach finishing has been found infeasible--see [Multiple Approach Surface Finishing](#)), use a rotational setup axis that provides obstructed access to the GCD, if one exists. Otherwise, the operation is infeasible.

If the operation is not part of a multi-approach operation sequence, check the following setup axes in this order:

- Rotational
- Principal
- User-activated

If none would (if used) render this GCD fully accessible, come back later to the feasibility check for this GCD and operation, if necessary. For now, move on to other operations for this GCD and then to operation assignment for all the other GCDs. Then, if the GCD remains unassigned, check the following setup axes for this GCD:

- All activated (non-principle, non-user-activated) nonrotational setup axes

If no activated setup axis would (if used) render the GCD fully accessible, the operation is infeasible.

- Side milling: the setup axis must be rotational and perpendicular to a tool approach that is parallel to the GCD.

If the operation is part of a multi-approach operation sequence (which is considered only after single-approach finishing has been found infeasible--see [Multiple Approach Surface Finishing](#)), use rotational setup axis that provides obstructed access with access to at least 2.5% of the surface, if one exists. Otherwise the operation is infeasible.

If the operation is not part of a multi-approach operation sequence, use a rotational setup axis that provides unobstructed access to the GCD, if one exists. If none exists, the operation is infeasible.

- Contouring: The setup axis must be one of the following:
 - Rotational and oblique to the GCD
 - Nonrotational and oblique (unobstructed) to the GCD

If the axis is rotational, there must be an unobstructed tool approach perpendicular to the rotational axis and oblique to the GCD.

Check the following setup axes in this order:

- Rotational
- Principal
- User-activated

If none would (if used) render this GCD accessible, come back later to the feasibility check for this GCD and operation, if necessary. For now, move on to other operations for this GCD and then to operation assignment for all the other GCDs. Then, if the GCD remains unassigned, check the following setup axes for this GCD:

- All activated (non-principle, non-user-activated) nonrotational setup axes

If no activated setup axis would (if used) render the GCD accessible, the operation is infeasible.

- General mill finishing: This operation's setup requirements are always considered feasible. APriori prefers a rotational axis that is perpendicular to a tool approach that is one of the following (in order of preference):
 - Normal unobstructed to the GCD
 - Parallel unobstructed to the GCD
 - Parallel obstructed to the GCD

If none exists, use the primary rotational setup axis.

- Undercut milling: This operation is never auto-evaluated; it must be explicitly user-included. This operation's setup requirements are always considered feasible. The setup axis is preferred be one of the following (in order of preference):
 - Rotational perpendicular to a tool orientation that is parallel obstructed to the GCD
 - Nonroational parallel obstructed to the GCD

Check the following setup axes in the following order:

- Rotational
- Principal
- User-activated

If none would (if used) render this GCD accessible, come back later to the feasibility check for this GCD and operation, if necessary. For now, move on to other operations for this GCD and then to operation assignment for all the other GCDs. Then, if the GCD remains unassigned, check the following setup axes for this GCD:

- All activated (non-principle, non-user-activated) rotational setup axes
- Chamfer milling: This operation is never auto-evaluated; it must be explicitly user-included. The operation's setup requirements are always considered feasible.
- Mill grooving: Chamfer milling: This operation is never auto-evaluated; it must be explicitly user-included. The operation's setup requirements are always considered feasible.
- Rough milling: This operation's setup requirements are always considered feasible. APriori prefers a rotational axis that is perpendicular to a tool approach that is one of the following (in order of preference):
 - Normal unobstructed to the GCD
 - Parallel unobstructed to the GCD
 - Parallel obstructed to the GCD

If none exists, use the primary rotational setup axis.

Curved Wall

- Indirect filleting: setup axis must be one of the following:
 - Rotational and perpendicular to tool approach that is normal to the GCD in such a way that this fillet can be produced by the corner of the tool
 - Nonrotational normal to the GCD in such a way that this fillet can be produced by the corner of the tool

Check the following setup axes in this order:

- Rotational
- Principal
- User-activated

If none would (if used) render this GCD fully accessible, come back later to the feasibility check for this GCD and operation, if necessary. For now, move on to other operations for this GCD and then to operation assignment for all the other GCDs. Then, if the GCD remains unassigned, check the following setup axes for this GCD:

- All activated (non-principle, non-user-activated) setup axes

If none would (if used) render this GCD fully accessible, the operation is infeasible.

- Rounding: setup axis must be one of the following:
 - Rotational perpendicular to a tool orientation that is oblique (unobstructed) to the GCD
 - Nonrotational oblique (unobstructed) to the GCD

Check the following setup axes in this order:

- Rotational

- Principal
- User-activated

If none would (if used) render this GCD accessible, come back later to the feasibility check for this GCD and operation, if necessary. For now, move on to other operations for this GCD and then to operation assignment for all the other GCDs. Then, if the GCD remains unassigned, check the following setup axes for this GCD:

- All activated (non-principle, non-user-activated) setup axes

If none would (if used) render this GCD accessible, the operation is infeasible.

- Facing: setup axis must be rotational and perpendicular to a tool orientation that is parallel (obstructed or unobstructed) to the GCD.
- Side Milling: the setup axis must be rotational and perpendicular to a tool approach that is parallel to the GCD.

If the operation is part of a multi-approach operation sequence (which is considered only after single-approach finishing has been found infeasible--see [Multiple Approach Surface Finishing](#)), use rotational setup axis that provides obstructed access with access to at least 2.5% of the surface, if one exists. Otherwise the operation is infeasible.

If the operation is not part of a multi-approach operation sequence, use a rotational setup axis that provides unobstructed access to the GCD, if one exists. If none exists, the operation is infeasible.

- Contouring: The setup axis must be one of the following:
 - Rotational perpendicular to a tool approach that is oblique (unobstructed) to the GCD
 - Nonrotational and oblique (unobstructed) to the GCD

Check the following setup axes in this order:

- Rotational
- Principal
- User-activated

If none would (if used) render this GCD accessible, come back later to the feasibility check for this GCD and operation, if necessary. For now, move on to other operations for this GCD and then to operation assignment for all the other GCDs. Then, if the GCD remains unassigned, check the following setup axes for this GCD:

- All activated (non-principle, non-user-activated) nonrotational setup axes

If no activated setup axis would (if used) render the GCD accessible, the operation is infeasible.

- General mill finishing: This operation's setup requirements are always considered feasible. APriori prefers a rotational axis that is perpendicular to a tool approach that is one of the following (in order of preference):
 - Parallel unobstructed to the GCD
 - Parallel obstructed to the GCD
 - Oblique unobstructed to the GCD

If none exists, use the primary rotational setup axis.

- Undercut milling: This operation is never auto-evaluated; it must be explicitly user-included. This operation's setup requirements are always considered feasible. The setup axis is preferred to be one of the following (in order of preference):
 - Rotational perpendicular to a tool orientation that is parallel obstructed to the GCD
 - Nonrotational parallel obstructed to the GCD

Check the following setup axes in the following order:

- Rotational
- Principal
- User-activated

If none would (if used) render this GCD accessible, come back later to the feasibility check for this GCD and operation, if necessary. For now, move on to other operations for this GCD and then to operation assignment for all the other GCDs. Then, if the GCD remains unassigned, check the following setup axes for this GCD:

- All activated (non-principle, non-user-activated) rotational setup axes
- Rough milling: This operation's setup requirements are always considered feasible. APriori prefers a rotational axis that is perpendicular to a tool approach that is one of the following (in order of preference):
 - Parallel unobstructed to the GCD
 - Parallel obstructed to the GCD
 - Oblique unobstructed to the GCD

If none exists, use the primary rotational setup axis.

- Thread milling: Setup axis must be one of the following:
 - Rotational perpendicular to a tool orientation that is parallel (unobstructed) to the GCD
 - Nonrotational parallel (unobstructed) to the GCD

Check the following setup axes in this order:

- Rotational
- Principal
- User-activated

If none would (if used) render this GCD accessible, come back later to the feasibility check for this GCD and operation, if necessary. For now, move on to other operations for this GCD and then to operation assignment for all the other GCDs. Then, if the GCD remains unassigned, check the following setup axes for this GCD:

- All activated (non-principle, non-user-activated) nonrotational setup axes

If none would (if used) render this GCD accessible, the operation is infeasible.

Curved Surface

- Indirect filleting: setup axis must be one of the following:

- Rotational perpendicular to tool orientation that is normal to the GCD in such a way that this fillet can be produced by the corner of the tool
- Nonrotational normal to the GCD in such a way that this fillet can be produced by the corner of the tool

Check the following setup axes in this order:

- Rotational
- Principal
- User-activated

If none would (if used) render this GCD accessible, come back later to the feasibility check for this GCD and operation, if necessary. For now, move on to other operations for this GCD and then to operation assignment for all the other GCDs. Then, if the GCD remains unassigned, check the following setup axes for this GCD:

- All activated (non-principle, non-user-activated) setup axes

If none would (if used) render this GCD accessible, the operation is infeasible.

- Rounding: Setup axis must be one of the following:
 - Rotational perpendicular to a tool orientation that is oblique (unobstructed) to the GCD
 - Nonrotational oblique (unobstructed) to the GCD

Check the following setup axes in this order:

- Rotational
- Principal
- User-activated

If none would (if used) render this GCD accessible, come back later to the feasibility check for this GCD and operation, if necessary. For now, move on to other operations for this GCD and then to operation assignment for all the other GCDs. Then, if the GCD remains unassigned, check the following setup axes for this GCD:

- All activated (non-principle, non-user-activated) setup axes

If none would (if used) render this GCD accessible, the operation is infeasible.

- Contouring: The setup axis must be one of the following:
 - Rotational perpendicular to a tool approach that is oblique (unobstructed) to the GCD
 - Nonrotational and oblique (unobstructed) to the GCD

Check the following setup axes in this order:

- Rotational
- Principal
- User-activated

If none would (if used) render this GCD accessible, come back later to the feasibility check for this GCD and operation, if necessary. For now, move on to other operations for this GCD and then to operation assignment for all the other GCDs. Then, if the GCD remains unassigned, check the following setup axes for this GCD:

- All activated (non-principle, non-user-activated) nonrotational setup axes

If no activated setup axis would (if used) render the GCD accessible, the operation is infeasible.

- General mill finishing: This operation's setup requirements are always considered feasible. APriori prefers a rotational axis that is perpendicular to a tool approach that is oblique unobstructed to the GCD. If none exists, use the primary rotational setup axis.
- Chamfer milling: This operation is never auto-evaluated; it must be explicitly user-included. The operation's setup requirements are considered feasible, if the GCD is a ruled curved surface (that is, if the surface could be generated by translational and rotational motion of a line segment through space).
- Rough milling: This operation's setup requirements are always considered feasible. APriori prefers a rotational axis that is perpendicular to a tool approach that is oblique unobstructed to the GCD. If none exists, use the primary rotational setup axis.

Simple Hole

All 4-axis mill operations on simple holes employ a setup axis that is one of the following:

- Rotational and perpendicular to a tool orientation that is parallel (obstructed or nonobstructed) to the hole's axis of symmetry.
- Nonrotational and parallel (obstructed or nonobstructed) to the hole's axis of symmetry.

Check the following setup axes in this order:

- Rotational unobstructed
- Rotational obstructed
- Principal unobstructed
- User-activated unobstructed
- All activated unobstructed
- Un-activated unobstructed
- Principal obstructed
- User-activated obstructed
- All activated obstructed
- Un-activated obstructed

If an un-activated setup axis would (if used) render the GCD accessible, activate it (assuming the operation is otherwise feasible). If none of the above setup axes would (if used) render the GCD accessible, consider the operation infeasible.

Note that Step Drilling (manually selected) is also supported for multistep holes. The drill is step-shaped and creates an entire multistep hole in a single operation. Step Drilling is very productive when many multistep holes must be cut.

5-Axis Mill

This section covers setup requirements for operations on the following GCD types:

- Planar Face
 - Curved Wall
 - Curved Surface
 - Simple Hole

When operations are alternatives of each other, the operations are listed in the order in which they are considered by aPiori (the order in which they are listed in the template).

The requirements below refer to the machine property **maxTiltAngle**.

Planar Face

- Facing: The setup axis must be one of the following:
 - Rotational and within **maxTiltAngle** of being normal to the GCD
 - Nonrotational and within **maxTiltAngle** of being normal to the GCD

If the operation is part of a multi-approach operation sequence (which is considered only after single-approach finishing has been found infeasible--see [Multiple Approach Surface Finishing](#)), use an activated setup axis that provides obstructed access to the GCD, if one exists. Otherwise, activate a setup axis that provides unobstructed access to the GCD.

Otherwise, check the following setup axes in this order:

- Rotational and within **maxTiltAngle** of being normal (unobstructed) to the GCD
- Principal and normal (unobstructed) to the GCD
- User-activated and normal (unobstructed) to the GCD
- Principal and within **maxTiltAngle** of being normal (unobstructed) to the GCD
- User-activated and within **maxTiltAngle** of being normal (unobstructed) to the GCD

If none would (if used) render this GCD accessible, come back later to the feasibility check for this GCD and operation, if necessary. For now, move on to other operations for this GCD and then to operation assignment for all the other GCDs. Then, if the GCD remains unassigned, check the following setup axes for this GCD:

- All activated nonrotational normal (unobstructed) to the GCD
- All activated nonrotational within **maxTiltAngle** of being normal (unobstructed) to the GCD

If no activated setup axis would (if used) render the GCD accessible, the operation is infeasible.

- Side milling: the setup axis must be one of the following:
 - Rotational and within **maxTiltAngle** of being parallel to the GCD
 - Nonrotational and parallel to the GCD

If the operation is part of a multi-approach operation sequence (which is considered only after single-approach finishing has been found infeasible--see [Multiple Approach Surface Finishing](#)), use an activated setup axis that provides unobstructed access to the GCD.

obstructed access with access to at least 2.5% of the surface, if one exists. Otherwise, activate a setup axis that provides obstructed access with access to at least 2.5% of the surface, if one exists.

Otherwise, check the following setup axes in this order:

- Rotational
- Principal
- User-activated

If none would (if used) render this GCD fully accessible, come back later to the feasibility check for this GCD and operation, if necessary. For now, move on to other operations for this GCD and then to operation assignment for all the other GCDs. Then, if the GCD remains unassigned, check the following setup axes for this GCD:

- All activated

If no activated setup axis would (if used) render the GCD fully accessible, the operation is infeasible.

- Contouring: the setup axis must be one of the following:
 - Rotational and within **maxTiltAngle** of being oblique (unobstructed) to the GCD
 - Nonrotational and oblique (unobstructed) to the GCD

Check the following setup axes in this order:

- Rotational
- Principal
- User-activated

If none would (if used) render this GCD accessible, come back later to the feasibility check for this GCD and operation, if necessary. For now, move on to other operations for this GCD and then to operation assignment for all the other GCDs. Then, if the GCD remains unassigned, check the following setup axes for this GCD:

- All activated

If no activated setup axis would (if used) render the GCD accessible, the operation is infeasible.

- General mill finishing: this operation's setup requirements are always considered feasible. aPriori prefers a rotational axis that is one of the following (in order of preference):
 - Normal unobstructed to the GCD
 - Normal obstructed to the GCD
 - Parallel unobstructed to the GCD
 - Parallel obstructed to the GCD
 - Oblique obstructed or unobstructed to the GCD

If none exists, use the primary rotational setup axis.

- Chamfer milling: this operation is never auto-evaluated; it must be explicitly user-included. The operation's setup requirements are always considered feasible.

- Mill grooving: Chamfer milling: This operation is never auto-evaluated; it must be explicitly user-included. The operation's setup requirements are always considered feasible.
- Rough milling: This operation's setup requirements are always considered feasible. APriori prefers a rotational axis that is one of the following (in order of preference):
 - Normal unobstructed to the GCD
 - Normal obstructed to the GCD
 - Parallel unobstructed to the GCD
 - Parallel obstructed to the GCD
 - Oblique obstructed or unobstructed to the GCD

If none exists, use the primary rotational setup axis.

Curved Wall

- Indirect filleting: setup axis must be one of the following:
 - Rotational that is within **maxTiltAngle** of being normal to the GCD in such a way that this fillet can be produced by the corner of the tool
 - Nonrotational normal to the GCD in such a way that this fillet can be produced by the corner of the tool

Check the following setup axes in this order:

- Rotational
- Principal
- User-activated

If none would (if used) render this GCD accessible, come back later to the feasibility check for this GCD and operation, if necessary. For now, move on to other operations for this GCD and then to operation assignment for all the other GCDs. Then, if the GCD remains unassigned, check the following setup axes for this GCD:

- All activated (non-principle, non-user-activated) setup axes

If none would (if used) render this GCD accessible, the operation is infeasible.

- Rounding: setup axis must be one of the following:
 - Rotational and within **maxTiltAngle** of being oblique (unobstructed) to the GCD
 - Nonrotational oblique (unobstructed) to the GCD

Check the following setup axes in this order:

- Rotational
- Principal
- User-activated

If none would (if used) render this GCD accessible, come back later to the feasibility check for this GCD and operation, if necessary. For now, move on to other operations for this GCD and then to operation assignment for all the other GCDs. Then, if the GCD remains unassigned, check the following setup axes for this GCD:

- All activated (non-principle, non-user-activated) setup axes

If none would (if used) render this GCD accessible, the operation is infeasible.

- Side milling: the setup axis must be one of the following:
 - Rotational within **maxTiltAngle** of parallel to the GCD
 - Nonrotational and parallel to the GCD

If the operation is part of a multi-approach operation sequence (which is considered only after single-approach finishing has been found infeasible--see [Multiple Approach Surface Finishing](#)), use an activated setup axis that provides obstructed access with access to at least 2.5% of the surface, if one exists. Otherwise, activate a setup axis that provides obstructed access with access to at least 2.5% of the surface, if one exists.

Otherwise, check the following setup axes in this order:

- Rotational
- Principal
- User-activated

If none would (if used) render this GCD accessible, come back later to the feasibility check for this GCD and operation, if necessary. For now, move on to other operations for this GCD and then to operation assignment for all the other GCDs. Then, if the GCD remains unassigned, check the following setup axes for this GCD:

- All activated (non-principle, non-user-activated) nonrotational setup axes

If no activated setup axis would (if used) render the GCD accessible, the operation is infeasible.

- Contouring: the setup axis must be one of the following:
 - Rotational within **maxTiltAngle** of oblique (unobstructed) to the GCD
 - Nonrotational and oblique (unobstructed) to the GCD

Check the following setup axes in this order:

- Rotational
- Principal
- User-activated

If none would (if used) render this GCD accessible, come back later to the feasibility check for this GCD and operation, if necessary. For now, move on to other operations for this GCD and then to operation assignment for all the other GCDs. Then, if the GCD remains unassigned, check the following setup axes for this GCD:

- All activated (non-principle, non-user-activated) nonrotational setup axes

If no activated setup axis would (if used) render the GCD accessible, the operation is infeasible.

- General mill finishing: this operation's setup requirements are always considered feasible. aPriori prefers a setup axis that is one of the following (in order of preference):
 - Rotational and parallel unobstructed to the GCD
 - Rotational and parallel obstructed to the GCD

- Rotational and oblique to a tool orientation that is parallel and unobstructed to the GCD
- Rotational and oblique to a tool orientation that is parallel and obstructed to the GCD
- Rotational and oblique to a tool orientation that is oblique and unobstructed to the GCD
- Nonrotational and oblique unobstructed to the GCD

If none exists, use the primary rotational setup axis.

- Rough milling: this operation's setup requirements are always considered feasible. aPriori prefers a setup axis that is one of the following (in order of preference):
 - Rotational and parallel unobstructed to the GCD
 - Rotational and parallel obstructed to the GCD
 - Rotational and oblique to a tool orientation that is parallel and unobstructed to the GCD
 - Rotational and oblique to a tool orientation that is parallel and obstructed to the GCD
 - Rotational and oblique to a tool orientation that is oblique and unobstructed to the GCD
 - Nonrotational and oblique unobstructed to the GCD

If none exists, use the primary rotational setup axis.

- Thread milling: the setup axis must be one of the following:
 - Rotational within **maxTiltAngle** of parallel (unobstructed) to the GCD
 - Nonrotational and parallel (unobstructed) to the GCD

Check the following setup axes in this order:

- Rotational
- Principal
- User-activated

If none would (if used) render this GCD accessible, come back later to the feasibility check for this GCD and operation, if necessary. For now, move on to other operations for this GCD and then to operation assignment for all the other GCDs. Then, if the GCD remains unassigned, check the following setup axes for this GCD:

- All activated (non-principle, non-user-activated) nonrotational setup axes

If no activated setup axis would (if used) render the GCD accessible, the operation is infeasible.

Curved Surface

- Indirect filleting: setup axis must be one of the following:
 - Rotational that is within **maxTiltAngle** of being normal to the GCD in such a way that this fillet can be produced by the corner of the tool
 - Nonrotational normal to the GCD in such a way that this fillet can be produced by the corner of the tool

Check the following setup axes in this order:

- Rotational
- Principal
- User-activated

If none would (if used) render this GCD accessible, come back later to the feasibility check for this GCD and operation, if necessary. For now, move on to other operations for this GCD and then to operation assignment for all the other GCDs. Then, if the GCD remains unassigned, check the following setup axes for this GCD:

- All activated (non-principle, non-user-activated) setup axes

If none would (if used) render this GCD accessible, the operation is infeasible.

- Rounding: setup axis must be one of the following:
 - Rotational and within **maxTiltAngle** of being oblique (unobstructed) to the GCD
 - Nonrotational oblique (unobstructed) to the GCD

Check the following setup axes in this order:

- Rotational
- Principal
- User-activated

If none would (if used) render this GCD accessible, come back later to the feasibility check for this GCD and operation, if necessary. For now, move on to other operations for this GCD and then to operation assignment for all the other GCDs. Then, if the GCD remains unassigned, check the following setup axes for this GCD:

- All activated (non-principle, non-user-activated) setup axes

If none would (if used) render this GCD accessible, the operation is infeasible.

- Side milling: the setup axis must be one of the following:
 - Rotational within **maxTiltAngle** of oblique (unobstructed) to the GCD
 - Rotational within **maxTiltAngle** of oblique obstructed to the GCD

If no rotational setup axis would (if used) render the GCD accessible, the operation is infeasible.

- Contouring: the setup axis must be one of the following:
 - Rotational within **maxTiltAngle** of oblique (unobstructed) to the GCD
 - Nonrotational and oblique (unobstructed) to the GCD

Check the following setup axes in this order:

- Rotational
- Principal
- User-activated

If none would (if used) render this GCD accessible, come back later to the feasibility check for this GCD and operation, if necessary. For now, move on to other operations for this GCD and then to operation assignment for all the other GCDs. Then, if the GCD remains unassigned, check the following setup axes for this GCD:

- All activated (non-principle, non-user-activated) nonrotational setup axes

If no activated setup axis would (if used) render the GCD accessible, the operation is infeasible.

- General mill finishing: this operation's setup requirements are always considered feasible. aPriori prefers a setup axis that is one of the following (in order of preference):
 - Rotational and oblique unobstructed to the GCD
 - Rotational and oblique obstructed to the GCD
 - Nonrotational and oblique unobstructed to the GCD

If none exists, use the primary rotational setup axis.

- Chamfer milling: This operation is never auto-evaluated; it must be explicitly user-included. The operation's setup requirements are considered feasible, if the GCD is a ruled curved surface (that is, if the surface could be generated by translational and rotational motion of a line segment through space).
- Rough milling: this operation's setup requirements are always considered feasible. APriori prefers a setup axis that is one of the following (in order of preference):
 - Rotational and oblique unobstructed to the GCD
 - Rotational and oblique obstructed to the GCD
 - Nonrotational and oblique unobstructed to the GCD

If none exists, use the primary rotational setup axis.

Simple Hole

All 5-axis mill operations on simple holes employ a setup axis that is one of the following:

- Rotational and within **maxTiltAngle** of being parallel (obstructed or unobstructed) to the hole's axis of symmetry.
- Nonrotational and parallel (obstructed or unobstructed) to the hole's axis of symmetry.

Check the following setup axes in this order:

- Rotational within **maxTiltAngle** of being parallel and unobstructed
- Rotational within **maxTiltAngle** of being parallel and obstructed
- Activated nonrotational within **maxTiltAngle** of being parallel and unobstructed
- Activated nonrotational parallel and unobstructed
- Un-activated nonrotational parallel and unobstructed
- Activated nonrotational parallel and obstructed
- Un-activated nonrotational parallel and obstructed

If an un-activated setup axis would (if used) render the GCD accessible, activate it (assuming the operation is otherwise feasible). If none of the above setup axes would (if used) render the GCD accessible, the operation is infeasible.

Note that Step Drilling (manually selected) is also supported for multistep holes. The drill is step-shaped and creates an entire multistep hole in a single operation. Step Drilling is very productive when many multistep holes must be cut.

2-Axis Lathe

All operations on a 2-axis mill require that the GCD's axis of symmetry is coincident with a turning axis.

3-Axis Lathe

A 3-Axis Lathe differs from a 2-Axis Lathe in that it can perform basic milling operations by means of live tooling, that is, electric motors mounted on the tool turret. This section covers setup requirements for operations on the following GCD types:

- Planar Face
- Curved Wall
- Curved Surface
- Simple Hole

When operations are alternatives of each other, the operations are listed in the order in which they are considered by aPriori (the order in which they are listed in the template).

Planar Face

- Mill facing: Some turning axis must be perpendicular or parallel to a tool orientation that is normal (unobstructed) to the GCD.
- Side milling: Some turning axis must be perpendicular or parallel to a tool orientation that is parallel (unobstructed) to the GCD.
- Contouring: Some turning axis must be perpendicular or parallel to a tool orientation that is oblique (unobstructed) to the GCD.
- General mill finishing: primary turning axis
- Rough milling: primary turning axis

Curved Wall

- Side milling: Some turning axis must be perpendicular or parallel to a tool orientation that is parallel (unobstructed) to the GCD.
- Contouring: Some turning axis must be perpendicular or parallel to a tool orientation that is oblique (unobstructed) to the GCD.

Curved Surface

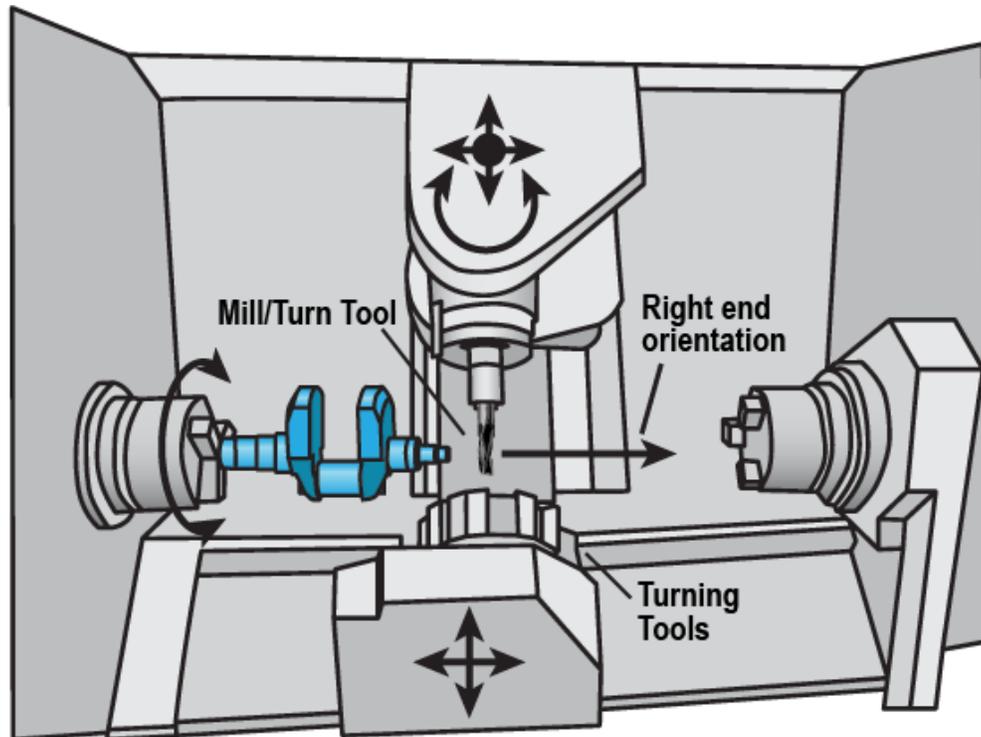
- Contouring: Some turning axis must be perpendicular or parallel to a tool orientation that is oblique (unobstructed) to the GCD.

Simple Hole

Some turning axis must be parallel or perpendicular to a tool orientation that is parallel (unobstructed) or parallel obstructed to the GCD.

Mill Turn

As with a 3-axis lathe, the aPriori-supported Mill Turn machine (sometimes called a 5-axis lathe) can perform both milling and turning operations. An example of this state-of-the-art machine is Mazak's Integrex series of machines.



This section covers setup requirements for operations on the following GCD types:

- Planar Face
- Curved Wall
- Curved Surface
- Simple Hole

When operations are alternatives of each other, the operations are listed in the order in which they are considered by aPriori (the order in which they are listed in the template).

Planar Face

- Mill facing: A turning axis must exist. There must be some tool orientation that is normal (unobstructed) to the GCD.
- Side milling: A turning axis must exist. There must be some tool orientation that is parallel (unobstructed) to the GCD.
- Contouring: A turning axis must exist. There must be some tool orientation that is oblique (unobstructed) to the GCD.

Curved Wall

- Side milling: A turning axis must exist. There must be some tool orientation that is parallel (unobstructed) to the GCD.
- Contouring: A turning axis must exist. There must be some tool orientation that is oblique (unobstructed) to the GCD.

Curved Surface

- Contouring: A turning axis must exist. Some tool orientation must be oblique (unobstructed) to the GCD.

Simple Hole

A turning axis must exist. Some tool orientation must be parallel (unobstructed) or parallel obstructed to the GCD.

11 2-Model Machining Process Group

This section describes the costing details and inputs available for the 2-Model Machining process group.

This chapter includes the following topics:

- Cost Model Overview
 - 2-Model Quick Start
 - Benefits of 2-Model Machining
 - A note about part alignment
 - A 2-Model Machining example
 - Transitioning to 2-Model
 - 2-Model GCDs
-

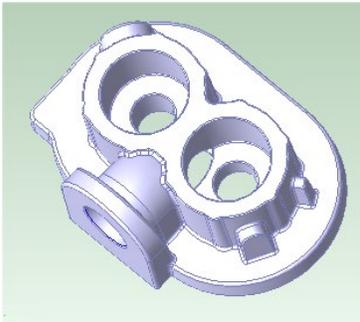
Cost Model Overview

The 2-Model Machining process group enables you to more accurately cost a part if you have:

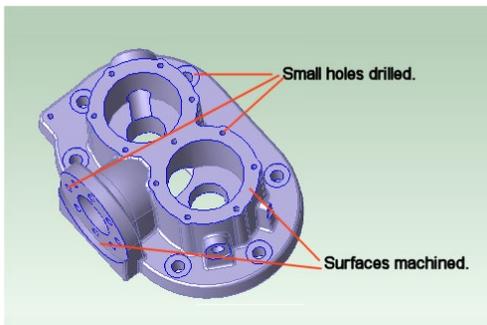
- One CAD model that represents the part after its initial processing (typically either a cast or forged part).
- A separate CAD model that represents the finished, machined part.

By comparing the two models, aPriori can automatically identify machined features and the amount of material removed, providing a highly accurate determination of the machining operations and cycle times required.

For example, you could have a model of a raw or unfinished part that is created from a casting or forging process, and which just provides the basic shape of the part, without small holes or finished surfaces or other details:



The finished model might include drilled holes and machined surfaces:



This makes the separately-licensed 2-Model Machining process group somewhat different than the other process groups in aPriori, since you are not costing a part from raw material through to final product. Rather, you are comparing two parts and determining the cost of getting from one to the other. aPriori creates GCDs based on differences between the finished and source models.

Note: You must ensure that the coordinate systems of both the source and the finished machine models are aligned. See *A note about part alignment on page 775*.

aPriori guides you through this costing process with the **Cost Guide** (see the "Initial costing: the Cost Guide" section of the aPriori *User Guide*). There are multiple ways you can approach this procedure. Typically, you will cost the source model, and then cost the finished model, using the source model as input. However, it is possible that you might

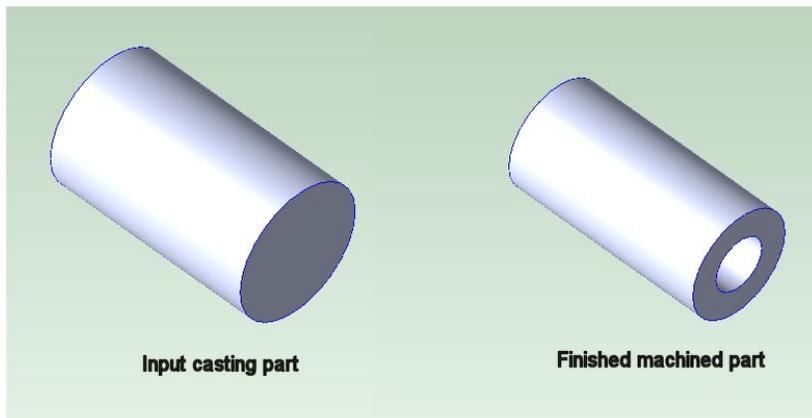
start with the finished model and not have the casting or forged model until later in the project. Or you may have a number of intermediate models (casting model, first machining model, second machining model, finished machining model). The examples below assume the typical case (costing the source model and then costing the finished machined model), though other approaches are also discussed.

Note that you must be CAD-file connected to *both* the source and finished CAD models in order to extract GCDs. If you change the source scenario specified in the Production Scenario tab of the Cost Guide, both the new source scenario and the current finished scenario should be CAD-file connected; if either is not, aPiori disables Save for the current finished scenario, and any subsequent costing relies on GCDs extracted using the old source scenario.

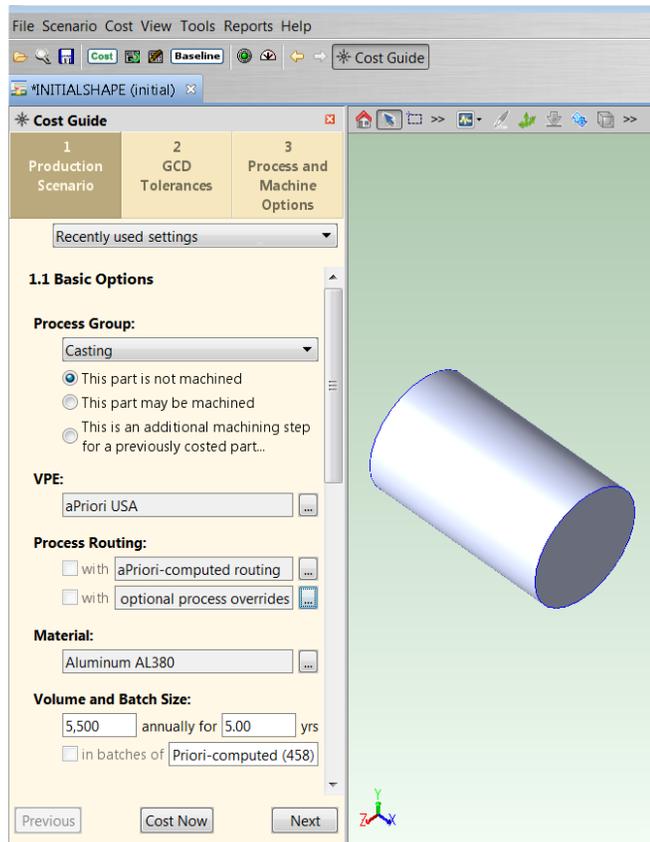
2-Model Quick Start

This section uses two very simple parts to outline the basic steps of 2-Model Machining. A more detailed example using the parts shown in the Overview above is presented in A 2-Model Machining example on [page 776](#).

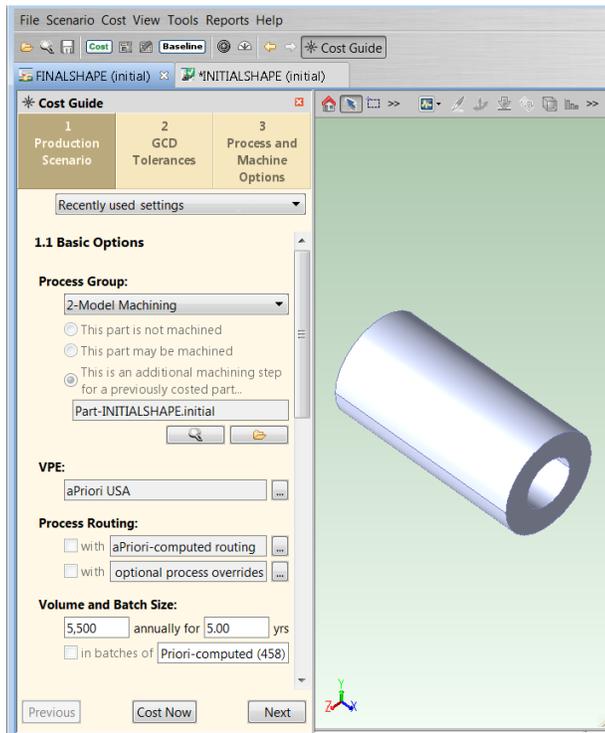
The input part is a simple cast cylinder. The finished part is created from the input part by turning the exterior and boring out the center:



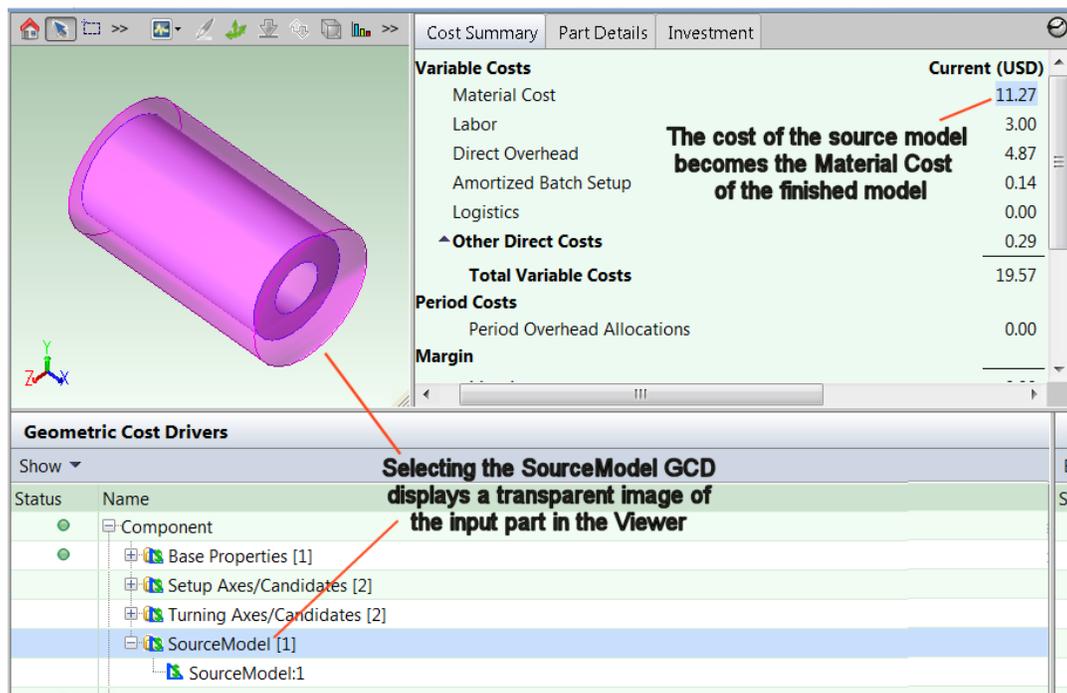
- 1 Open the CAD file for the source model (the input casting part) and in the **Cost Guide** assign it to the **Casting** process group. (If it was a forged part, you would assign it to the **Forging** process group.) Assume that the defaults for all the other settings are okay and cost it.



- 2 Open the CAD file for the finished model (the finished machined part), and in the **Cost Guide** assign it to the **2-Model Machining** process group. Use the **Search** (magnifying glass) button to bring up the **Search Tool** and specify the source model that you costed in the previous step (see the "Using the Search Tool" section of the aPriori *User Guide*). Again, assume that the default values for all the other settings are okay for this example and click the **Cost Now** button.



aPriori compares the source model and the finished model and extracts GCDs that represent the difference between the two models – that is, volumes of material that are assumed to be removed by machining. By default, the **Fully Burdened Cost** of the source part is represented as the **Material Cost** of the machined part. However, aPriori provides a plant variable named `useSourceModelIFBCAsMaterialCost` that allows you to change this behavior. If you set this plant variable to `false`, aPriori uses the **Piece Part Cost** of the source part as the **Material Cost** of the machined part.



Note that you must be CAD-file connected to *both* the source and finished CAD models in order to extract GCDs. If you change the source scenario specified in the Production Scenario tab of the Cost Guide, both the new source scenario and the current finished scenario should be CAD-file connected; if either is not, aPriori disables Save for the current finished scenario, and any subsequent costing relies on GCDs extracted using the old source scenario.

Benefits of 2-Model Machining

In addition to the separately-licensed 2-Model Machining group, aPriori also supports costing machined castings and forgings for which only a single CAD model is available. This section describes the difference between the two approaches, and why you may want to consider 2-Model Machining.

When only a single CAD model is available, aPriori uses various configurable heuristics to:

- Determine which features and operations are machined vs. cast or forged.
- Estimate the amount of material removed.
- Compute cycle times and costs.

For example, in Casting, aPriori assumes that holes that are smaller than a specified threshold value are machined rather than cast. For surfaces that are machined, aPriori assumes a certain depth of material has been removed by the machining operation in order to compute machining cycle times. In cases where the aPriori determinations do not match actual practice, you may override operation assignments and other inputs. However, manually selecting individual GCDs and ensuring that override values are correctly entered can be time-consuming and prone to error. The advantage of the 2-Model Machining process group is that the amount of user review and override required is greatly minimized, since comparisons of the raw and machined part eliminates aPriori “guesswork”.

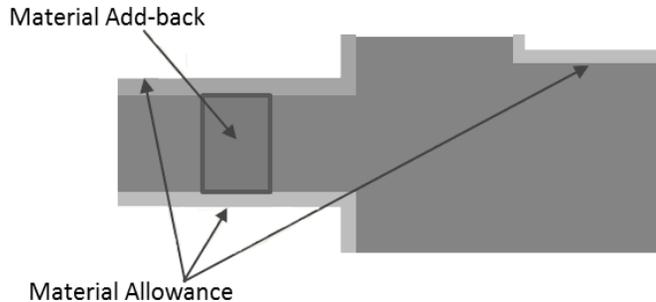
For example, consider the outline of the final part shown in the following illustration:



The starting point for this part might resemble this:



But if you have only one CAD model showing the machined end product, aPriori has no information about what the starting point for the raw casting or forging actually looks like. In this case, aPriori tries to calculate an estimated starting point by adding back some uniform amount of material to surfaces that it determines are machined. (This “material add back” is done in the Casting and Forging process cost models.)



In contrast, when you use 2-Model machining, you supply two CAD models to aPriori, eliminating the need for this potentially inaccurate back-calculation of the starting point.

By using 2-Model Machining, you get a much more accurate costing of the initial model, followed by an accurate costing of the actual machining of the finished details. The 2-Model Process Group allows aPriori to automatically identify:

- GCDs that are produced by the finishing processes rather than the primary processes –eliminating the need for users to manually identify them.
- The actual amount of material that is removed by the finishing processes -- leading to more accurate cycle time and cost calculations.

Note: 2-Model Machining actually uses the same machining cost model that is available in the **Casting** and **Forging** process templates as a secondary machining process. However, in 2-Model Machining, the GCDs available to the machining cost model are different because aPriori recognize the differences in geometry between the source and the finished models.

A note about part alignment

aPriori requires that the two CAD models have a common “base” coordinate system. This is because aPriori will align the two CAD models using their base coordinate systems, and then attempt to determine the differences between them.

To check for misalignment

There are three ways to check whether the CAD models use the same base coordinate system:

- 1 In the CAD system, ensure that both models are aligned the same way. (Specific procedures are beyond the scope of this aPriori documentation.) Doing this and correcting any problems before you attempt the 2-Model Machining costing is the preferred way to avoid this issue.

- 2 In aPriori, visually inspect the Source Model GCD (see Source model GCD on page 781). This can only be done after you have attempted to cost the finish-machined model. It is better to use the CAD system method described in the previous paragraph, prior to costing. But if you have already costed the parts, click the Source Model GCD to display it, and see if it appears to be positioned correctly with respect to the finish machined model.
- 3 In aPriori, check the Costing Error messages. Again, this can only be done after you have already attempted to cost the finish-machined model. aPriori displays a Costing Error message similar to: **“Parts are seriously misaligned. Source and final CAD models must be aligned on the same coordinate system”** in the **Manufacturing Process** pane if it believes that too great a percentage of the finished model protrudes beyond the boundaries of the source model, indicating a likely misalignment of their respective base coordinate systems. By default this threshold is set to 18%, but can be controlled by the plant variable **Misalignment Cutoff Percent**.

To correct misalignment

If the source model and finish machined model do not use a common base coordinate system, you must correct this situation inside the CAD system. Specific steps are beyond the scope of this documentation, but consider the following discussion when deciding the approach you should take in your CAD system:

Typically, the finish-machined CAD model is created by first merging in the geometry of the raw (unmachined) part, and then adding in a variety of cuts and hole features to represent the material that is machined away.

If your finish machined model was created in such a manner, then you can use this to your advantage to create a new model of the raw (unmachined) part that will have the same base coordinate system as the finished model. To do this:

- 1 Save a copy of the CAD file to a new name.
- 2 Suppress or delete the features that occur AFTER the merge of the raw unmachined geometry.
- 3 Save the file again. At this point, the geometry of the new CAD file should look identical to the CAD file that represents the raw/unmachined part, but it will have the same base coordinate system as the machined part.
- 4 In aPriori, cost this new CAD file in Casting, Forging, or whatever process group is appropriate, and supply its scenario as the “Source” model instead of the original CAD file.
- 5 Repeat the steps described in “To check for misalignment” above to verify that the misalignment has been resolved.

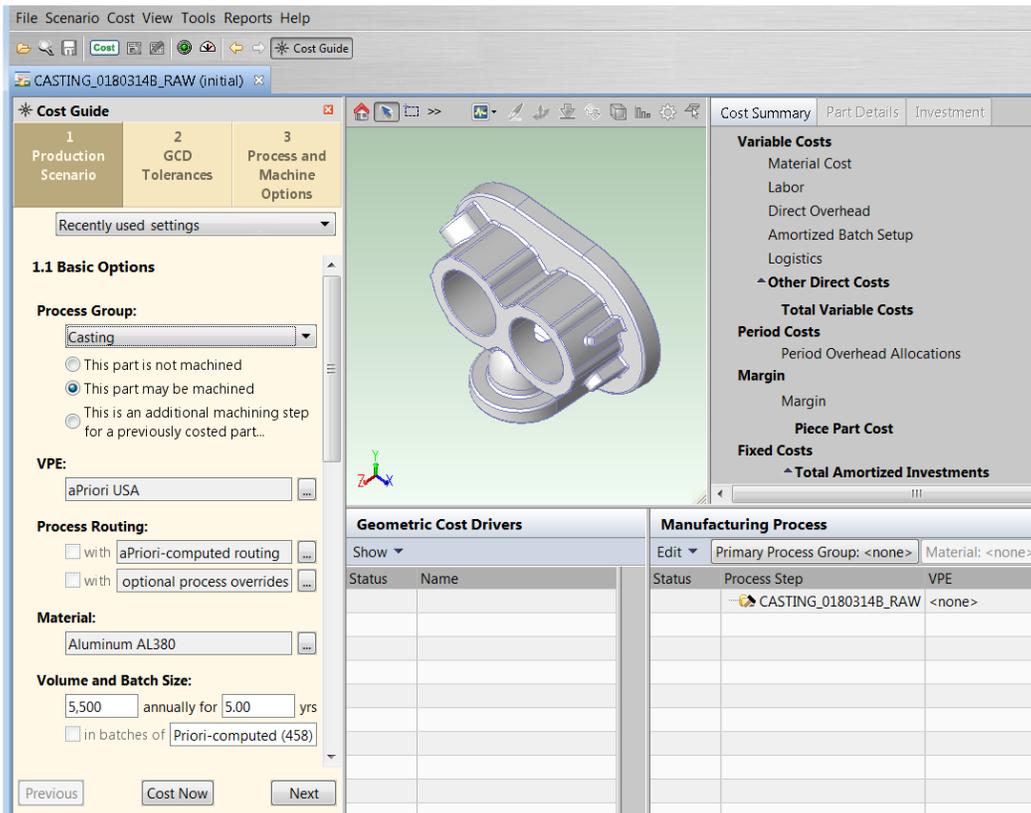
A 2-Model Machining example

This procedure goes into more detail than the Quick Start above, and illustrates more advanced uses of the **Cost Guide** for costing the parts described in the Overview..

Although this process follows the recommended order of steps for 2-Model Machining (open and cost the source model first, then open the finished model and specify the costed source model, then cost the finished model), other approaches are also discussed.

Cost the input source model

- 1 Open the CAD file for the source model and cost it in the appropriate process group. For this example, we will be using Casting. In the **Cost Guide** assign it to the **Casting** process group.



Unlike the Quick Start example above, this example will explore some of the other **Cost Guide** options available to 2-Model Machining. You may notice that when you switch to the Casting process group, the **Cost Guide** displays three additional options in the Process Group section:

This part is not machined

This part may be machined

This is an additional machining step for a previously costed part

If you know the CAD model represents an unmachined Casting or Forging, then you should select **This part is not machined**. aPriori will NOT assign machining to the part if this radio option is chosen. However, it still will warn you if it determines that there are GCDs that cannot be manufactured without machining, such as small holes or surfaces with tight tolerance and surface finish requirement. In this case, GCDs will fail rather than being assigned a machining operation.

These options are provided only for three process groups:

Casting

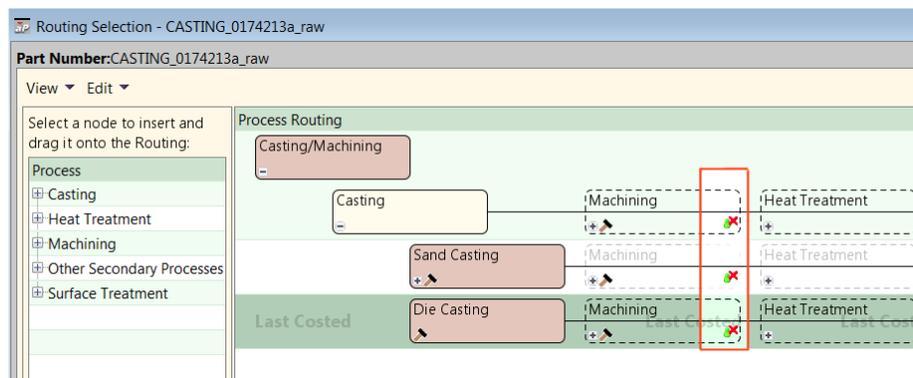
Forging

2 Model Machining (displayed, but grayed)

Specify **This part is not machined** when you are costing a casting or forging part and you know for certain that it will become the input part for the **2- Model Machining** process group. This option disables any secondary machining process from being routed within the **Casting** or **Forging** process group, but still evaluates the feasibility of the casting or forging process.

Note: With this setting, it is possible for aPiori to determine that a GCD is infeasible for casting or forging if machining is excluded. This includes things like small holes, high-quality tolerances, etc. that cannot be achieved via Casting or Forging alone.

You can see the results of this setting after you cost the model and then access the **Customize Routing** feature available from **Edit > Routing Selection** in the **Manufacturing Process** panel. The machining processes are marked with a red "x" over the user override symbol, indicating that they are not available:



If you are costing a part that represents a machined casting or forging, and you do not have a distinct CAD model of the raw casting or forging, then choose the second radio option (**This part may be machined**). Similarly, if you are not sure if the part has features that must be machined, choose the second radio option..

The setting **This is an additional machining step for a previously costed part** automatically changes your process group to **2-Model Machining**. It is provided as a convenience to users who think about their finished model as a forging or a casting which needs to be machined, rather than leaping to the realization that it should be designated a **2-Model Machining** part. For example, assume that you open the finished model, but knowing how it was created, you specify the **Casting** or **Forging** process group. When you click **This is an additional machining step for a previously costed part**, the **Cost Guide** changes your process group to **2-Model Machining**.

- 2 Use the **Cost Guide** to enter any other cost inputs for the parts, including production volumes and attributes. See the "Initial costing: the Cost Guide" section of the aPiori *User Guide* for more details about using the **Cost Guide**.

- 3 Similarly, if you need to adjust tolerances before costing the part, you can click **Next** and proceed to the **GCD Tolerances** tab of the **Cost Guide**.

Note: When you have only a single CAD model, tolerance settings are one of the inputs that will drive aPiori to add Machining if needed to achieve the specified tolerance. In the 2-Model environment, aPiori often can tell that machining is present simply because of the differences between the CAD models. So it may not be as critical to enter tolerance values in order to drive machining. However, in the case of tight tolerances and surface finish requirements, specifying the tolerances still is recommended as it may drive a specialized machining operations such as grinding as well as milling and turning operations.

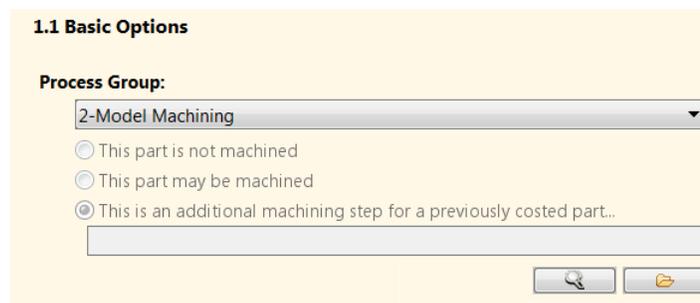
- 4 At this point you must perform an initial costing before you can proceed. Click **Cost Now** at the bottom of the **Cost Guide** (or click the **Cost** button in the aPiori toolbar).
- 5 After this initial costing, check for any error or warning messages and address them if necessary. Once you have a good costing, you can optionally proceed to the "Process and Machine Options" and address any Process Setup Options (PSOs) or Machine Selection issues and re-cost. Again, these step are not specific to 2-Model Machining. Once you have a good costing for the source part, you can proceed to the finish-machined model.

Cost the finished model

- 1 Click **File > Open CAD File** to open the finished model, and in the **Cost Guide** assign it to the **2-Model Machining** process group.

Note: As discussed in the previous step, if you initially assign it to **Forging** or **Casting** because that is the way you think about the part, you could now click **This is an additional machining step for a previously costed part** and the **Cost Guide** will automatically switch to **2-Model Machining**.

When you select **2-Model Machining**, aPiori automatically selects the third radio option (**This is an additional machining step**) and disables the other radio options. Also, the **Cost Guide** displays some new fields for selecting the Source model .



1.1 Basic Options

Process Group:

2-Model Machining

This part is not machined

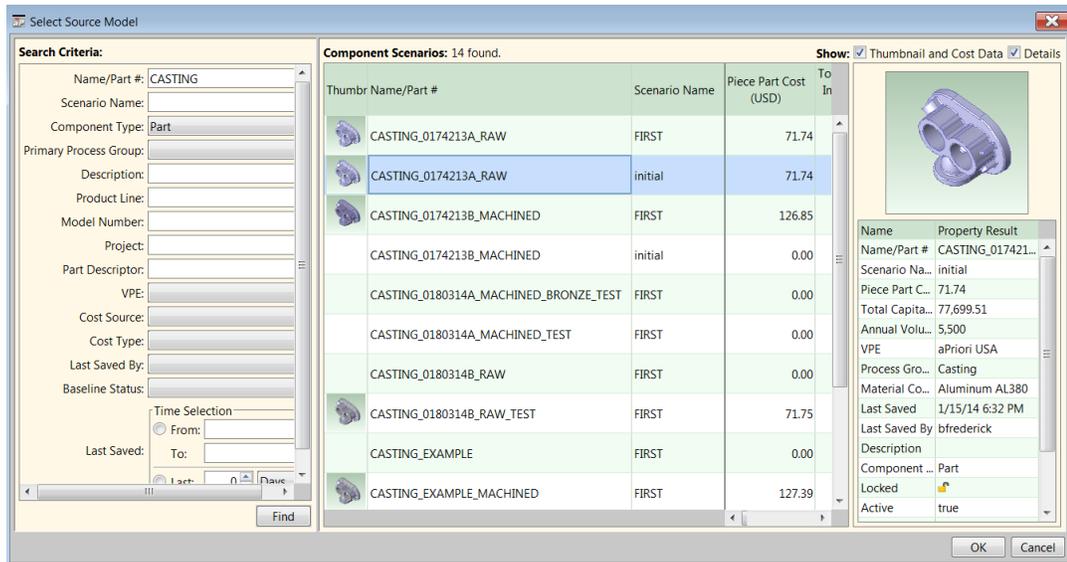
This part may be machined

This is an additional machining step for a previously costed part...

[Search] [Next]

- 2 If you have already costed the input model (as in this example), use the Search (magnifying glass) button to bring up the **Search Tool** and specify the correct scenario for the source model (see the "Using the Search Tool" section of the aPiori *User Guide*). For example, you might have one scenario costing the source model with the

USA VPE, and another costing it with the Mexico VPE. Make sure that you select the correct scenario.



Note: If the source model is not yet costed, you can use the **Uncosted CAD** button to navigate to and open the CAD file, after which you can perform the steps described above for *Cost the input source model*. Then return here to complete the costing of the finished model. And if you do not yet have a source model at all, you can still cost the finished model and incorporate the input model when it becomes available (see *Transitioning to 2-Model* on page 780),

At this point, your 2-Model part is costed. As noted above, by default the **Fully Burdened Cost** of the source part is represented as the **Material Cost** of the machined part. But you can modify plant variable `useSourceModelFBCAsMaterialCost` to cause aPriori to use the **Piece Part Cost** of the source part as the **Material Cost** of the machined part. To visually inspect the model, see *Source model GCD* below.

Transitioning to 2-Model

In some cases you may want (or need) to start from a single CAD part and then transition to 2-Model later. For example, you may have the finished model CAD file in hand, but the forging or casting input model CAD file may not be available for another month. In this case, you can proceed by costing the finished model by using the Casting or Forging process group and specifying tolerances and/or machining operations for specific GCDs as appropriate.

Or perhaps you have a legacy part that you costed in the Casting or Forging process group, including tolerance and surface roughness information for many GCDs.

In either case, when the raw input CAD model becomes available, you can switch the existing model to the 2-Model Machining process group, and specify the newly-available cast or forged part to be the source model.

When you switch the process group from Casting or Forging to 2-Model Machining, aPriori attempts to preserve the GCD numbering and any user overrides assigned to those GCDs, such as tolerance and roughness requirements. However, you should check the **Cost Overrides Summary** dialog (see the "Working with the Overrides Summary

dialog" section of the aPriori *User Guide*) to ensure that no significant overrides have been lost.

2-Model GCDs

The 2-Model Machining process group introduces two GCDs that are extracted in addition to the other GCDs used in the Machining cost model:

- source model
- flat

The 2-Model Machining process group also introduces a new property “Is Stock Surface” for planar face, curved wall, and curved surface GCDs.

For information about machining GCDs that are not specific to 2-Model Machining, see *Stock Machining and Machining Process Groups* on page 495.

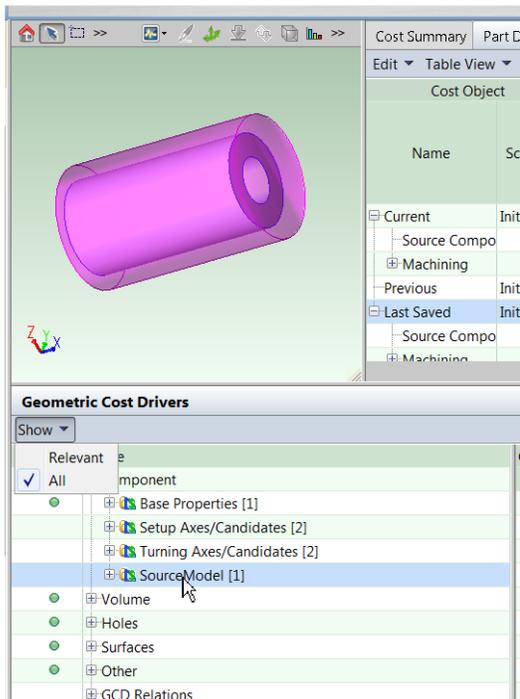
Source model GCD

The source model GCD allows you to visualize the difference between the initial raw part (the “source” model”) and the finished machined part by displaying a transparent representation of the source model while you are viewing the finished model.

To view the results of the simple 2-Model Machining costing described above:

- 1 Ensure that the costed 2-Model Machining part is open.
- 2 In the **Geometric Cost Drivers** panel, expand the **Component** GCD in the **Name** column.
- 3 Click **SourceModel** in the **Name** column.

The component viewer updates to display the finished part, with the volume of the initial part highlighted in magenta around it.

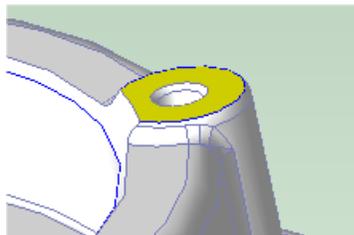


Flat GCD

The *flat* GCD applies only to 2-Model Machining, and represents geometry that is typically spot-faced (for example, to clean off a surface so that it mates better with another part or fastener). It typically is generated only for geometry that is milled and not turned, as Ring GCDs typically will be generated for turned geometry.

The Flat GCD has three properties: Depth, Volume, and Removed Volume. Removed Volume defines a volume with a planar bottom and (optionally) walls that are vertical and orthogonal to the bottom, and represents the source part material removed to reveal the machined surface. For example, you might have a boss that rises vertically above a surface. 2-Model Machining determines that since the part cannot be turned along the axis of the boss, the volume that needs to be milled away to reach the top surface of the boss should be represented by a flat rather than a ring.

Note that in the component viewer, only the planar bottom of a selected flat is highlighted (as a surface) to simplify the display, even though a flat actually has volume. In the example below, the flat actually includes the volume rising orthogonally above the highlighted surface.



The 2-Model Machining process group also has some configurable logic about how to extract GCDs corresponding to machined hole features.

If the diameter of a hole is below a threshold defined by site variable **Maximum Turned Hole Diameter**, aPuri extracts it as a partially-filled simple hole equal in shape to the simple

hole in the final CAD model. This permits it to be machined with typical hole-making operations such as drilling. However, if it is bigger than the threshold, aPriori extracts it as a ring that partially fills the simple hole in the final CAD model, assuming that it is to be turned.

GCD property “Is Stock Surface”

The GCD property **Is Stock Surface** set to “true” only if the surface (planar face, curved wall, or curved surface) of the finished model is coincident with a surface of the source model.

The screenshot shows a software interface with a CAD model on the left and a 'Geometric Cost Drivers' table on the right. The table has the following columns: Status, Name, GCD Name, er..., On Boun..., Is on End, Direction Type, Is Stock Surface, Approac..., Approac..., and Fille. The 'Is Stock Surface' column for CurvedWall:179 is circled in red and set to 'false'.

Status	Name	GCD Name	er...	On Boun...	Is on End	Direction Type	Is Stock Surface	Approac...	Approac...	Fille
Component	Base Properties [1]	CurvedWall:168	0.00	false	false	Parallel	true	NONE	NONE	
	Setup Axes/Candida	CurvedWall:169	-	false	false	Parallel	true	NONE	NONE	
	SourceModel [1]	CurvedWall:170	-	false	false	Parallel	true	NONE	NONE	
	Volume	CurvedWall:171	-	false	false	Parallel	true	NONE	NONE	
	Holes	CurvedWall:172	-	false	false	Parallel	true	NONE	NONE	
	Surfaces	CurvedWall:173	-	false	false	Parallel	true	NONE	NONE	
	Planar Faces [87]	CurvedWall:174	-	false	false	Parallel	true	NONE	NONE	
	Curved Walls [180]	CurvedWall:175	-	false	false	Parallel	true	NONE	NONE	
	Curved Surfaces [16]	CurvedWall:176	0.00	false	false	Oblique	true	NONE	NONE	
	Other	CurvedWall:177	-	false	false	Oblique	true	NONE	NONE	
		CurvedWall:178	-	false	false	Parallel	false	NONE	NONE	
		CurvedWall:179	-	false	false	Parallel	false	NONE	NONE	
		CurvedWall:180	1.00	false	false	Oblique	true	NONE	NONE	

12 Sheet Metal—Hard Tooled

The Sheet Metal process group lets you estimate manufacturing times and costs for a wide variety of sheet metal fabrication processes and subsequent machining operations. aPriori's sheet metal process models include estimates of hard tooling costs. This chapter describes the costing details and inputs that are available for various hard-tooled Sheet Metal processes. For detailed information on soft-tooled processes, see the chapter [Sheet Metal—Soft Tooled](#). See also [Sheet Metal—Hydroforming](#), [Sheet Metal—Transfer Die](#), and [Sheet Metal—Stretch Forming](#).

This chapter includes the following topics:

- [Cost Model Overview for Hard Tooled Sheet Metal](#)
 - [GCD Extraction for Hard Tooled Sheet Metal](#)
 - [Routing and Feasibility for Hard Tooled Sheet Metal](#)
 - [User Inputs for Hard Tooled Sheet Metal](#)
 - [Design-to-cost Configuration for Sheet Metal](#)
-

Cost Model Overview for Hard Tooled Sheet Metal

This overview section summarizes assumptions and limitations of the following aspects of the model:

- Hard Tooled Sheet Metal General Process
- Part Geometry for Hard Tooled Sheet Metal
- Materials
- Material Utilization and Part Nesting for Hard Tooled Sheet Metal
- Machines for Hard Tooled Sheet Metal
- Tooling for Hard Tooled Sheet Metal

Hard Tooled Sheet Metal General Process

The aPriori Sheet Metal models support the following broad types of hard-tooled routings:

- Stage Tooling routings
- Tandem Die routings
- Progressive Die routings
- Standard Press routings
- Transfer Die routings (covered in Sheet Metal—Transfer Die)

These types of routings differ from one another with the regard to the following important factors (among others):

- Whether they use multiple presses (each with a single die) or a single press (that contains multiple dies)
- Whether the transfer of parts from die to die is manual or automatic.

The following table specifies these factors for each routing type:

<i>Routing Type</i>	<i>Presses: Single Vs. Multiple</i>	<i>Transfer: Manual Vs. Automatic</i>
Stage Tooling	Multiple	Manual
Tandem Press	Multiple	Automatic
Progressive Die	Single	Automatic
Standard Press	Single	Manual
Transfer Die	Single	Automatic

Stage Tooling

Stage Tooling uses multiple presses (each with a single die) and manual transfer between presses. Each press performs a single operation on each part, in a defined sequence. The die sequence is typically comprised of some combination of a blanking

die, forming die, cut-off die, piercing die, coining die, and/or trim die. Stage tooling can be cost effective for small quantity part needs.

The number of stages required to form a given part is generally based on the number of bends and holes in the part, and the order in which they must be created. Stage Tooling presses are the same as those used for Standard Press routings (see below). The tools tend to be simple, and a number of them can be incorporated within a die.

Tandem Die

Tandem Die uses multiple presses (each with a single die) and automated transfer between presses. Tandem Die is similar to Stage Tooling, except that it uses automated transfer instead of manual transfer.

Progressive Die

Progressive Die uses a single press (with multiple dies) and automated transfer between dies. All necessary stations are mounted on a single, common die set, and parts are transferred via a carrier strip with pilot holes.

Progressive die is a high volume sheet metal manufacturing process in which coil stock is fed through a sequence of stations, each of which performs a set of operations. Progressive die, like stage tooling, groups operations into stages (called *stations* in progressive die) by evaluating precedence and compatibility rules. However, whereas in stage tooling each stage corresponds to a separate machine, in progressive die all stations are housed within the same machine.

The progressive die process provides support for features and practices commonly used in automotive sheet metal manufacturing. These include deep draw forming operations, side-action forming (cam-actuated), support for multiple trim stages, and support for performing (hole) piercing operations prior to or subsequent to bending and forming operations, as well as additional options for specifying strip layouts and indicating concurrent stamping of multiple parts. These options generally are not available for stage tooling. Some large parts and parts that are very deeply drawn might be better handled by transfer die—see [Sheet Metal—Transfer Die](#).

Standard Press

Standard Press uses a single press with multiple dies which are “switched over” for batch manufacturing of different operations (so only one die is used at a time). The Standard Press represents a batch manufacturing approach in which a single press is used to perform a certain type of operation on all parts in the batch, and then the die is switched out and replaced with another die to perform the next type of operation to all parts.

Standard presses vary greatly in size and can create complicated shapes out of large and small sheets of metal. The standard press is generally used for lower volume parts. In contrast, progressive die is generally used for high volume parts and assumes single-part flow.

Transfer Die

Transfer Die uses a single press that contains multiple die sets. Transfer dies are special line dies that are timed together and properly spaced an even distance apart in a single press. The distance between each die is referred to as the *pitch*, or the distance the part must travel between stations. Parts are automatically transferred between stations/dies

along special traveling rails mounted within the press boundaries. See [Sheet Metal—Transfer Die](#) for more information.

Possible operations in the various routing types include the following:

- Blanking
- Embossing
- Piercing
- Scoring
- Restriking
- Bending
- Coining
- Extruding
- Trimming
- Shear Forming
- Cam Overbending
- Countersinking
- Double Bending
- Gusset Bending
- Deep Drawing

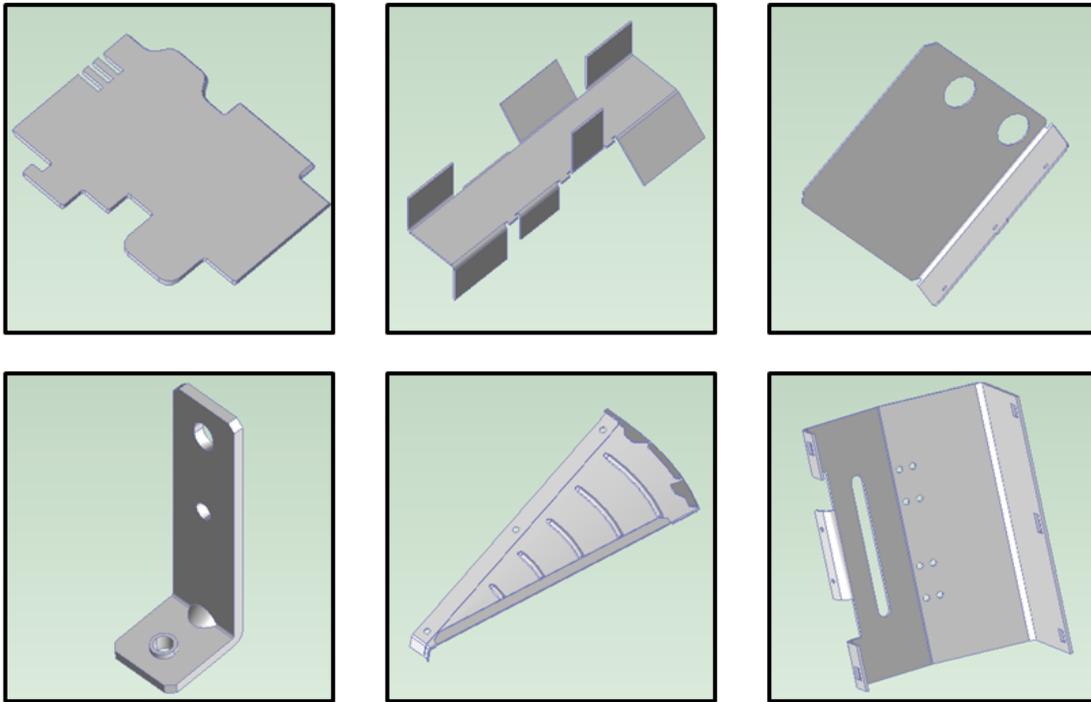
The hard-tooled stamping processes all are available via a separately licensed module.

If you have licensed the appropriate modules, your routing can include optional machining, turning, heat treatment, surface treatment, and packaging processes.

See [Routing and Feasibility for Hard Tooled Sheet Metal](#) for more information.

Part Geometry for Hard Tooled Sheet Metal

A small selection of example parts is shown below.



Geometry extraction for the sheet metal process group identifies some sheet-metal-specific features:

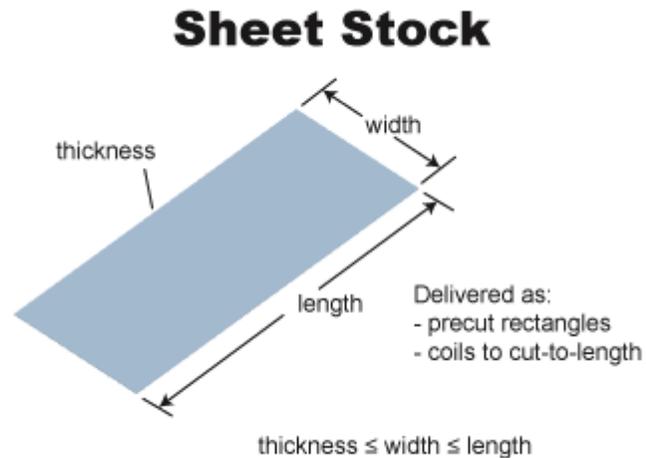
- Blank GCD for Hard Tooled Sheet Metal
- Main Surface for Hard Tooled Sheet Metal
- LIES_OUTSIDE Relation for Hard Tooled Sheet Metal
- Peninsular Ratio Property for Hard Tooled Sheet Metal
- Cam Bundling for Hard Tooled Sheet Metal

In addition to solid CAD models, the Sheet Metal process group supports surface CAD models, which represent surfaces only, rather than solid geometry. See [Surface-only CAD Models for Sheet Metal](#).

See [GCD Extraction for Hard Tooled Sheet Metal](#) for more information.

Materials and Stock Forms for Hard Tooled Sheet Metal

All sheet metal processes, except Progressive Die, assume the use of sheet stock. Standard sheet thicknesses vary depending on the material selected. Aluminum, for example, ranges from 0.45 mm in thickness to 6.35 mm, while steel ranges from 0.42 mm to 160 mm. Widths are available in 4 ft or 5 ft. Lengths are available in 8 ft or 10 ft.



The Progressive Die process assumes the use of virtual coil stock. Stock width is based on the results of the strip nesting calculations—see [Material Utilization and Part Nesting](#), [Blank GCD](#), and [Blank XY Orientation within Part Strip](#). Stock thickness is based on part thickness.

Note to VPE Administrators: Actual coil stocks are *not* supported. If you add stock to a sheet metal VPE, *do not* select **COIL** as the stock form.

Materials include the following:

- Aluminum: 3003, 5052, 6061
- Copper: 110
- Galvanized Steel: HR-1010, HR-1012, HR-1020
- Stainless Steel: 304, 316, 316L
- Steel: CR-1010, CR-1012, CR-1020, HR-1010, HR-1012, HR-1020

Material composition details include the following:

- Unit Cost (USD / kg)
- Density (kg / m³)
- Shear Strength (MPa)
- Ultimate Tensile Strength (MPa)

Material details include equivalent DIN and EN name standards for use with regional VPEs.

Material stock details include the following:

- Thickness (mm)
- Width (mm)
- Length (mm)
- Unit Cost (USD / kg)

Note: If you change the selected material for a part, the part's CAD file must be accessible to aPriori so that it can recalculate the flattened part outline.

Material Utilization and Part Nesting for Hard Tooled Sheet Metal

The material cost of a sheet metal part is based on the rough mass required to make the part. The utilization is equal to the finish mass of the part divided by the rough mass—rough mass includes any material scrap.

aPriori provides multiple methods for computing sheet metal material utilization. By default, aPriori uses different methods for different kinds of processes:

- For progressive die, aPriori uses a true-part shape nesting (TPSN) algorithm by default. In order to maximize material utilization and minimize waste, this algorithm finds the tightest nesting for parts using the blank's actual perimeter. Note that the TPSN algorithm used by progressive die (and transfer die—see [Sheet Metal—Transfer Die](#)) differs from the TPSN algorithm used by soft-tooled processes (see [Sheet Metal—Soft Tooled](#)) in the following respect:
 - Progressive die: uses an optimized strip-nesting algorithm in which parts are nested in rows, and all parts in a row have consistent orientations.
 - Soft-tooled: allows neighboring parts to have different orientations, and doesn't constrain parts to be organized into rows.
- For other hard-tooled routings (that is, hard-tooled routings other than progressive die), aPriori uses rectangular nesting by default. This algorithm considers length-wise and width-wise orientations using the blank's smallest enclosing rectangle.

The **Material Selection** dialog (in the Manufacturing Process pane) provides you with four options for calculating utilization:

- **Rectangular Nesting:** assumes the part is rectangularly nested on a sheet, with either a lengthwise or widthwise orientation (whichever is more efficient).
- **True-Part Nesting:** for progressive die, uses the component's actual perimeter to determine nesting, and tests various rotations of the component. See also [Blank XY Orientation within Part Strip](#) for more information on progressive die strip nesting.
- **Machine Default:** uses the current machine's associated average material utilization (the machine property **Avg Utilization**); use this to estimate material costs for dynamic nesting.
- **Override:** uses a fixed utilization value entered by user; use this when you know the exact utilization based on a supplier's nesting pattern.

VPE administrators can customize the default utilization method with the cost model variable **defaultUtilizationMethod**.

The current nesting pattern on the currently selected stock is viewable in the Viewer using the **Analysis** menu. The stock can be changed via the **Material Selection** dialog.

Setup options for controlling trip strips, margins, and addenda are available—see [User Inputs for Hard Tooled Sheet Metal](#).

Machines for Hard Tooled Sheet Metal

The following tables list important machine property value ranges. Ranges are listed below for those processes that support a choice of machines in the starting point VPEs:

Progressive Die Press

Property	Low End	High End
Press Force (kN)	658.0	9,964.0
Max Part Length (mm)	703.0	5,181.6
Max Part Width (mm)	609.60	2,590.8
Shut Height (mm)	330.0	1,372.0

Stage Press, Standard press, Tandem Press

Property	Low End	High End
Max Part Length (mm)	703.0	3,403.6
Max Part Width (mm)	609.6	1,501.14
Press Force (kN)	658.0	6,636.0

Tooling for Hard Tooled Sheet Metal

A part's tooling costs for stage tooling, progressive die, transfer die, and tandem die depend, among other things, on the number of stages or stations required to produce the part. The required number of stages or stations depends on the following factors:

- GCD proximity: GCDs that lie too close together must be made at different stages or stations.
- GCD direction: GCDs that share the same direction that are not too close can be made at the same stage or station.
- Operation precedence: Operations that cannot be performed at the same time or that need to follow an order of precedence cannot be made at the same stage or station. For example, piloting must occur on the first station and cannot be combined with forming or bending..

Based on the number-of-stations analysis, aPiori determines which features will be manufactured at each stage. Once all features have been associated with a stage, aPiori calculates the tool base and tool shop cost for the entire tool based on the part size and feature set.

For Generic Press, Progressive Die, Std Press, and Tandem Press, the tooling model estimates the number of parts that can be produced with a given tool before it wears to the point that it needs to be replaced. Based on that estimate, the cost model determines the number of tools required to manufacture the production volume specified in the Production Scenario tab of the Cost Guide, and accounts for that number of tools in total hard tooling cost.

Tool-life estimation is based on part material, and adjusted for tool material and tool coating type. See [Tool Life for Sheet Metal](#). For a given costing, either the formula Dependencies or Investment tab displays the number of tools assumed by tooling cost calculations.

Bill of material costs include the following:

- Die Blocks
- Die Shoes
- Punch Holders
- Top/Bottom Parallels
- Top Plate
- Trans Plate
- Punch Pads

- Strippers
- Rubber
- Spring
- Hardware
- Ejectors
- Guide Pins
- Pilots
- Round Risers
- Bumpers
- Rounds
- Bushings
- Punches
- Inserts
- Tapping Units

Labor costs include the following:

- Assembly
- CNC Machining
- CNC Programming
- Debug
- Design
- Drilling
- Grinding
- Lathe
- Milling
- Rework
- Sawing
- Wire EDM

Standard press tooling costs include the cost of all dies required to manufacture the part. The **Investment** tab for a part shows a breakdown of die costs, which may include dies for blanking, piercing, forming, drawing, and cam actuated overbending. Each die's cost includes (1) the cost of the die base plus (2) the cost of the tool shop. The cost for all dies is based on:

- Area of the blank (that is, area within the flattened-part outline)
- Part thickness
- Features on the part, including the holes, bends, and forms

Customizing Tooling Costs for Hard Tooled Sheet Metal

Following is a selection of some important, controllable factors that affect tooling costs:

- Number of die stations. For progressive die, the following setup options affect the number of die stations:
 - Pierce Before or After Forms
 - Add IDLE Station Before CUTOFF Station

- Add IDLE Station Following TRIMMING Station if Blank Pitch is Less Than This
- Enable SCORING Operations for Bends
- Enable COINING Operations for SimpleHoles
- Enable SHAVING Operations for SimpleHoles
- Enable Restriking Operation for Straight and Curved Bends
- Enable Standalone Piloting Operation
- Set Number of Trimming Operations
- Enable In Die TAPPING operations
- Add Idle Station Before After Tapping
- Add Idle Station After Trimming
- Add Idle Station After Cam Forming
- Add Idle Station After Cam Trimming
- Add Idle Station After Cam Bending
- Add Idle Station After Cam Piercing

You can also specify the number of die stations directly by editing the number of occurrences of the Die Station component-level operation (for progressive die) or the Generic Press process (for stage tooling).

- Blank XY orientation. By default, parts are oriented in the XY plane so as to maximize material utilization. You can sometimes decrease tooling cost by overriding the default and reorienting the part so as to decrease the blank pitch. This might decrease tooling costs by decreasing the overall length of the die stations—though possibly at the expense of increasing material cost (due to less efficient utilization). For progressive die, you can control the part orientation with the setup option [Blank XY Orientation within Part Strip](#). See also [Material Utilization and Part Nesting for Hard Tooled Sheet Metal](#).
- Main surface. The choice of main surface (see [Main Surface for Hard Tooled Sheet Metal](#)) affects tooling cost by requiring or eliminating tooling components (such as lifters for down bends). You can modify the default choice of main surface with the main surface tool, , in the Viewer toolbar.
- Number of concurrent parts. In starting point VPEs, one part at a time is stamped at each station, by default. Stamping two parts concurrently can decrease cycle time and material cost, but it can increase tooling cost. For progressive die, you can control concurrency with the setup option [Number of Parts Stamped Concurrently](#).
- Hole piercing before or after forming. The setup option [Pierce Before or After Forms](#) controls whether hole-piercing precedes or follows forming operations, which can affect both number of stations and the number of cams.

Tooling Details for Hard Tooled Sheet Metal

The Sheet Metal Process tooling model provides an itemized tooling cost estimate, including a detailed tooling BOM. Individual estimates for tooling cost per stage or station including material and labor for each stage or station are provided.

An itemized estimate for the following output variables may be found in the **Investments** tab:

- Die Properties
 - Blank Length
 - Blank Width
 - Die Width
 - Number of Dies or Stages
 - Number of Parts per Hit
- Labor Cost
 - Bottom Parallels
 - Die Blocks
 - Die Shoes
 - Forming Punches
 - Misc. Die Components (\$)
 - Perforators
 - Piercing Punches
 - Punch Holders
 - Punch Pads
 - Strippers
 - Top Parallels
 - Top Plate
 - Trans Plates
- Machining Labor
 - Base Tool Hours
 - CNC Machining Hours
 - CNC Programming Hours
 - Drilling Hours
 - EDM Hours
 - Grinding Hours
 - Lathe Hours
 - Milling Hours
 - Sawing Hours
- Material Cost
 - Bottom Parallels
 - Die Blocks
 - Die Shoes
 - Forming Punches
 - Misc Die Components (\$)
 - Perforators
 - Piercing Punches
 - Punch Holders
 - Punch Pads
 - Strippers
 - Top Parallels

- Top Plate
- Trans Plate
- Tooling Cost per Stage - Material & Labor
- Total Tool
 - Material Cost
 - Adjustment
 - Assembly Cost
 - Design Cost
 - Labor Cost
 - Markup
 - Rework Cost
 - Tryout/Debug Cost

Tool Life for Sheet Metal

For Transfer Die and Offline Blanking, the tooling model estimates the number of parts that can be produced with a given tool before it wears to the point that it needs to be replaced. Based on that estimate, the cost model determines the number of tools required to manufacture the production volume specified in the Production Scenario tab of the Cost Guide, and accounts for that number of tools in total hard tooling cost.

Tool-life estimation is based on part material, and adjusted for tool material and tool coating type, as follows:

- 4 To determine an unadjusted value for the number of parts that can be produced by a single tool, the cost model looks up this number by part material in the lookup table **tblToolLife**.

Material Type	Num Parts Per Tool
Aluminum	17,500,000.00
Copper	17,500,000.00
Galvanized Steel	3,000,000.00
Heat Resistant Super Alloys	625,000.00
Low-Alloy Steel	3,000,000.00
Stainless Steel	750,000.00
Steel	3,000,000.00
Titanium	100,000.00
Unalloyed Steel	3,000,000.00

- 5 The result is then adjusted for mold material by multiplying it by the tool shop property **Tool Life Factor** for the current mold material (see [Base Tool Material](#)).
- 6 That result is then adjusted for mold coating by multiplying it by the **Tool Life Improvement Factor** looked up lookup in the table **tblToolCoating** by coating type (see [Plating of Die Components](#)).

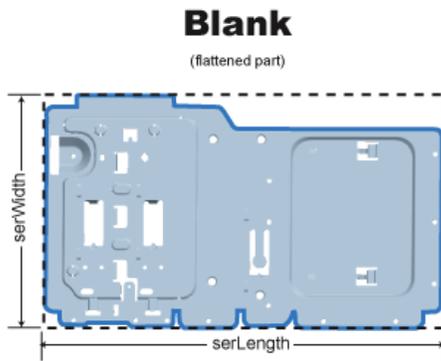
Coating Cost Factor (USD / kg)	Coating Type	Tool Life Improvement Factor
0.00	None	1.00
1.90	Tribo-coating	1.10
2.80	Electroless Nickel	1.40
3.50	Electroless Teflon	1.70
4.10	Nitrided Steel	1.90
4.40	Electroplated Chromium	2.00
6.90	Plasma Sprayed	3.00
18.20	PVD TiN	7.20
19.10	CVC TiC	7.50
26.60	DuplexVariantic	14.40

For a given costing, either the formula Dependencies or Investment tab displays the number of tools assumed by tooling cost calculations.

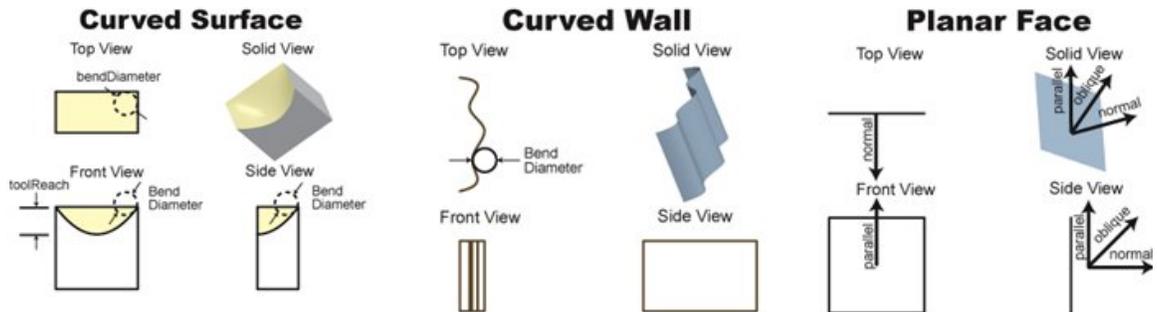
GCD Extraction for Hard Tooled Sheet Metal

aPriori extracts the geometry of a CAD model in the form of geometric cost drivers (GCDs) that include surfaces and holes, as well as bending and forming GCDs, lances, and a GCD that represents the flattened blank from which the sheet metal part is formed. As usual, there is a special GCD, **Component**, which represents the part as a whole. Below are some of the important properties of each of these GCD types. Each GCD's units are shown in metric.

- **Component:**
 - Volume (mm³)
 - Surface Area (mm²)
 - Length, Width, and Height (millimeters)
 - Number of Surfaces
 - Min Thickness, Max Thickness, and Avg Thickness (millimeters)
 - Length Direction, Width Direction, and Height Direction: each of these is a unit vector, two of whose components are 0 (the other component is 1 or -1). These vectors can be compared with the Direction vector of another GCD (such as a Setup Axis) in order to determine whether the GCD's direction is aligned with the part's length, width, or height.
- **Blank:**
 - Perimeter (millimeters)
 - SER Length and SER Width (smallest enclosing rectangle dimensions in millimeters)
 - Thickness (millimeters)
 - Straight Length (millimeters)

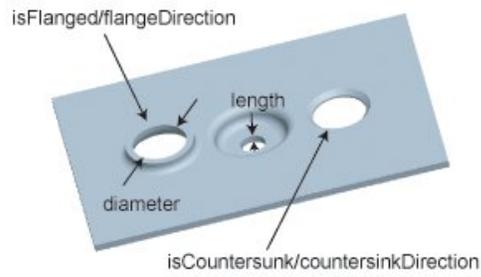


- **Surfaces (Curved Surface, Curved Wall, and Planar Face):**
 - Finished Area (mm²)
 - Bend Diameter (millimeters)
 - Perimeter (millimeters)
 - SER Length and SER Width (smallest enclosing rectangle dimensions in millimeters)
 - Corner Diameter (millimeters)
 - Inside Diameter (millimeters)
 - Number of Surfaces
 - Fillet Min Angle and Fillet Max Angle (degrees)
 - Round Radius (millimeters)
 - Round Length (millimeters)
 - Wall Corner Diameter (millimeters)

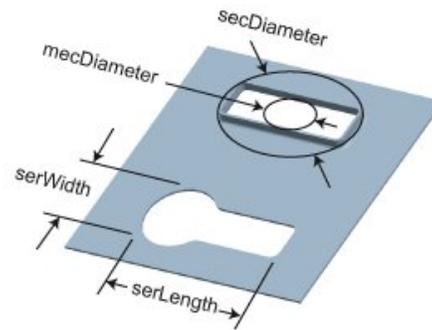


- **Holes (Simple Hole, Complex Hole):**
 - Diameter (millimeters),
 - Length and Depth (millimeters)
 - Volume (mm³)
 - Surface Area (mm²)
 - Hole type (THROUGH or BLIND)
 - Blind, Sleeve Pin, Threaded, Countersunk, and Flanged (TRUE or FALSE)

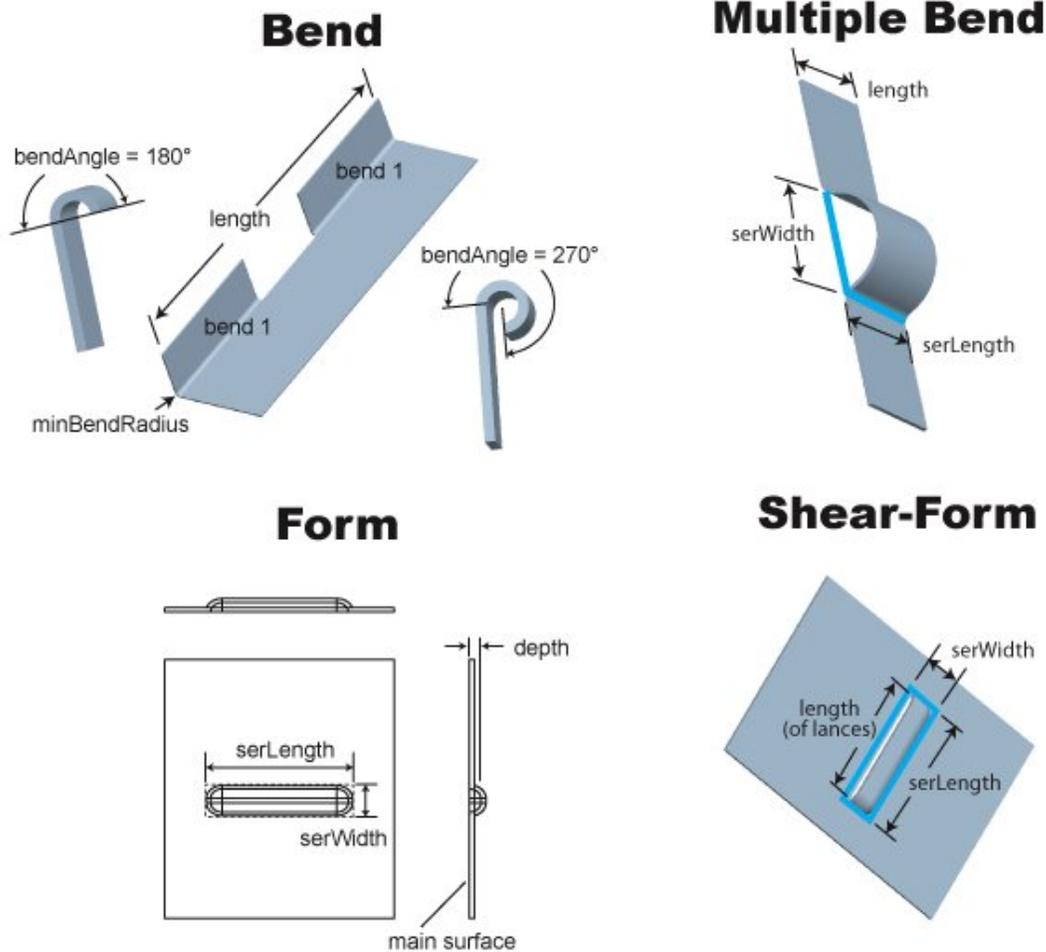
Simple Hole



Complex Hole



- **Bending/Forming (Bend, Multi Bend, Form, Shear-Form):**
 - Bend Angle (degrees)
 - Length (millimeters)
 - Bend Flap Size (millimeters)
 - Min Bend Radius (millimeters)
 - SER Length (millimeters)
 - SER Width (millimeters)
 - Perimeter (millimeters)



- **Lance:**
 - Length (millimeters)

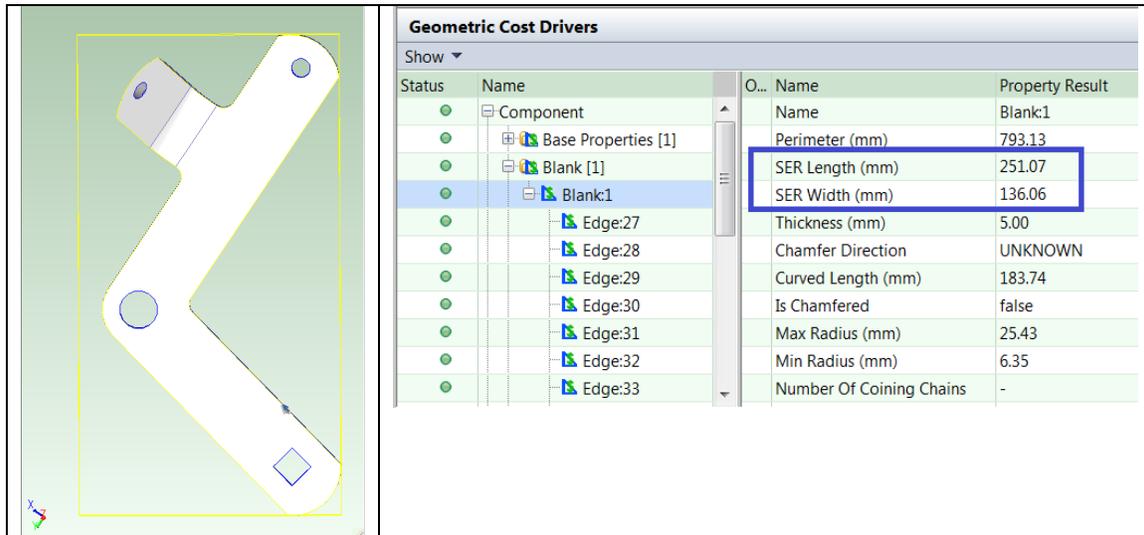
You can modify Form GCDs by adding or removing surfaces, and you can define a new Form GCD by specifying the included surfaces—see [Creating and Editing Forms](#).

More information on special sheet metal GCDs and properties is contained in the following sections:

- Blank GCD for Hard Tooled Sheet Metal
- Main Surface for Hard Tooled Sheet Metal
- LIES_OUTSIDE Relation for Hard Tooled Sheet Metal
- Peninsular Ratio Property for Hard Tooled Sheet Metal
- Cam Bundling for Hard Tooled Sheet Metal
- Surface-only CAD Models for Sheet Metal

Blank GCD for Hard Tooled Sheet Metal

The Blank GCD is specific to the Sheet Metal process groups. It represents the flattened part. Its properties (such as **Perimeter**, **Thickness**, **SER Length**, and **SER Width**) are listed in the Geometric Cost Drivers pane, and are all *independent* of the blank's orientation on the stock sheet or coil.



You can display the flat pattern head on, in a separate window, together with its associated SER, by selecting **Flat Outline** from the Analysis menu in the Viewer toolbar.

Blank SER/SWER Lenth and Width Versus Blank Pitch and Coil Width

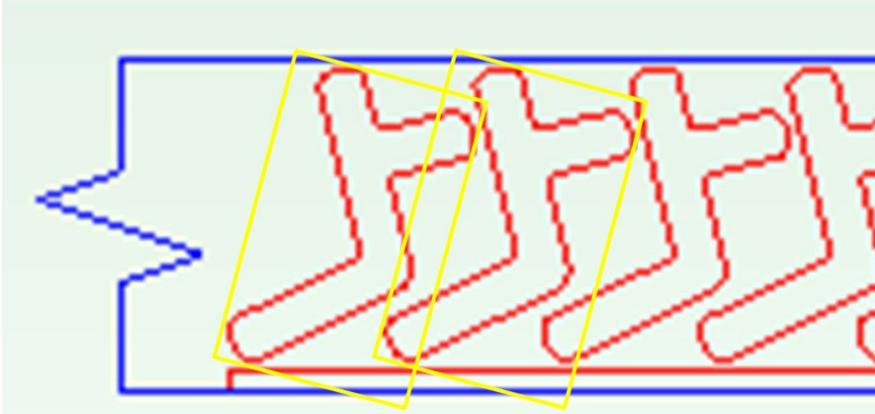
It is very important to distinguish between the following two rectangles that enclose the flattened part:

- Blank's SER: this is the smallest possible rectangle that contains all of the flattened part. Its dimensions are independent of the blank's orientation on the stock sheet or coil, that is, **SER Length** and **SER Width** do not change if the blank's nesting or orientation change.
- Nested blank's extent rectangle: this is a rectangle that
 - Contains all of the flattened part
 - Has sides that are each either parallel or perpendicular to the pitch direction (direction of coil flow) or sheet length.
 - Encloses extra material around the flattened part for various purposes, such as carrier strips and cutting strips.

The dimensions of this extent rectangle *do* depend on the blank's orientation on the coil; these dimensions can change if the orientation changes.

Some users might be used to using the term "blank" to refer to the extent rectangle described above; but this is *not* how the term "blank" is used in aPriori. In the aPriori interface and documentation, "blank" refers to the flattened part, whose **SER Width** and **SER Length** are independent of nesting and orientation.

The figure below shows nested blanks oriented on the stock coil. The blank SERs are shown in yellow.



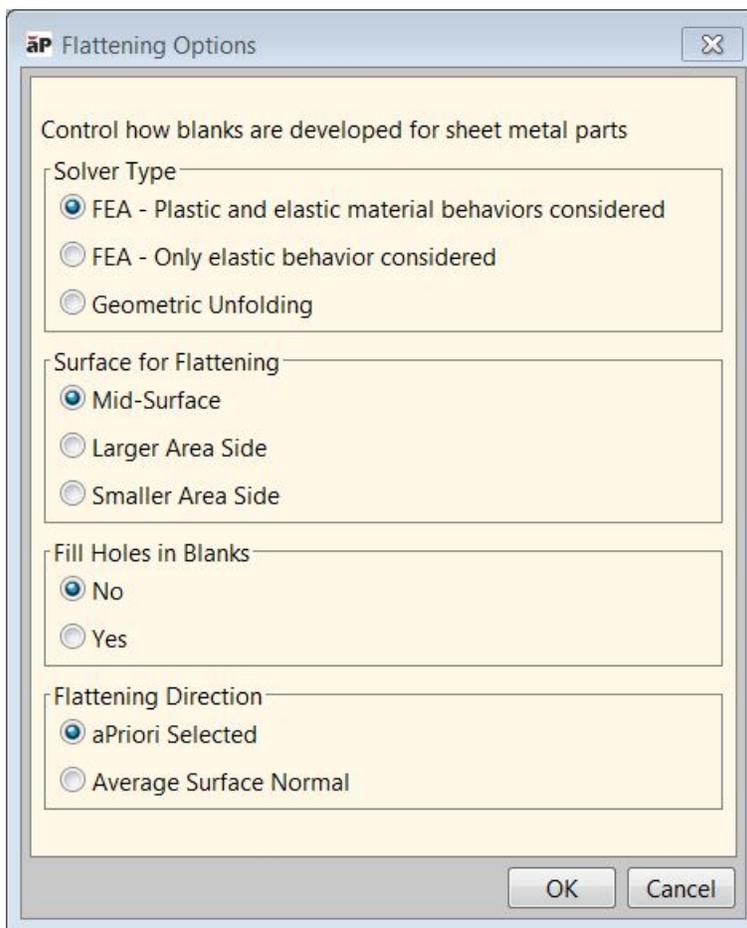
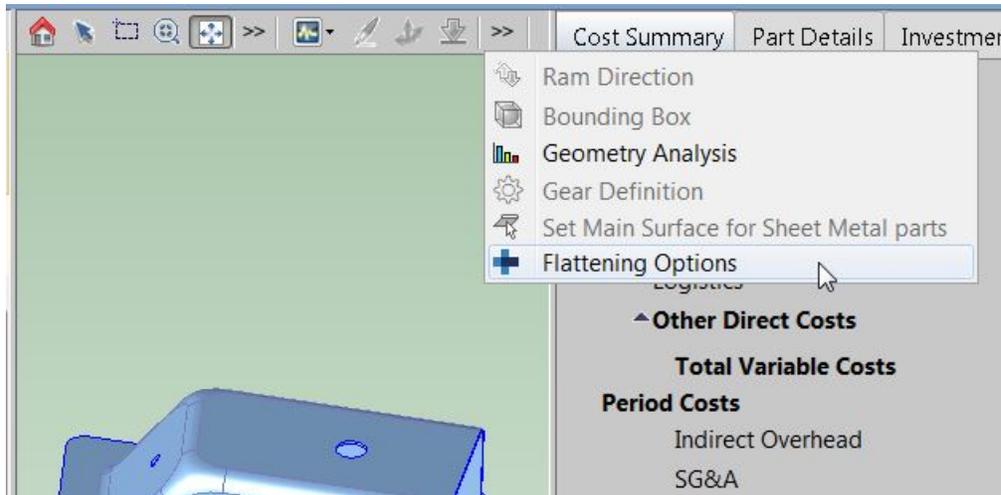
Flattening for Hard-tooled Sheet Metal

aPriori provides two alternative methods for determining the outline of the flattened part, finite element analysis (FEA)-based flattening and geometric flattening:

- FEA flattening:
 - Analysis is based on a forming simulation which uses a finite element analysis derived from the part's CAD model and the properties of the selected material.
 - More accurate than geometric flattening for formed and drawn automotive components and similar complex stampings.
 - Generally slower than geometric flattening (very complex parts sometimes require more than one minute to flatten, although the great majority require far less time).
- Geometric flattening:
 - Analysis is based on unfolding of CAD model geometry, and neither takes into account material properties nor simulates the forming process.
 - Accurate for “mostly developable” parts, that is, parts consisting primarily of flat planar surfaces and simple bent or rolled surfaces, with a few small, isolated deformed features like gussets and stiffening beads. These types of parts are common in the agriculture/construction equipment and hi-tech industries.
 - Generally faster than FEA flattening.

FEA flattening is used by default in starting point VPEs. VPE administrators can customize this default with the site variable **flatteningSolverType**.

For a given part, you can override the default flattening method, or configure FEA flattening, with the Flattening Options dialog, which is available from the Viewer toolbar.



The dialog provides the following options:

- **Solver Type:**
 - FEA – Plastic and elastic material behaviors considered: takes into account both the elasticity-related material properties (including Young’s modulus and Poisson’s ratio) and the plasticity-related material properties (including K, the strain-hardening coefficient, N, the strain-hardening exponent, and R, the Lankford parameter, average) . This is the default in starting point VPEs.

- FEA – Only elastic behaviors considered: takes into account only the elasticity-related material properties (including Young’s modulus and Poisson’s ratio). Because only elastic behavior is modeled, blank size estimates are slightly larger with this option than with the “Plastic and elastic” option. Some users prefer this approach as it is slightly more conservative for estimating material usage and costs.
- Geometric Unfolding: Select this if you don’t want to use FEA flattening.

The **Flattening Method** property of the Blank GCD indicates the method used for the most recent geometry extraction. It’s possible values are FEA_PLASTIC, FEA_ELASTIC, GEOMETRIC_UNFOLDING.

Geometric Cost Drivers			
Show ▾			
Status	Name	O... Name	Property Result
●	Component	Num Edges	17
●	Base Properties [1]	Num Sharp Corners	-
●	Blank [1]	Straight Length (mm)	1,138.65
●	Blank:2	Flattening Method	FEA_PLASTIC
●	Edge:79	Worst Peninsular Ratio	0.00
●	Edge:80	Worst Peninsular Rati...	0.00
●	Edge:81	Requested	<auto-select>
●	Edge:82	Selected	Blanking / Direct Trimmin...

VPE administrators can customize the default solver type with the site variable **flatteningSolverType**.

- Surface for Flattening: applies to FEA flattening only. FEA flattening proceeds by imposing a mesh on an overall surface of the part. The mesh serves to divide the part into a large but finite number of discrete elements.
 - Mid-Surface: specifies that the mesh should be imposed midway between one side of the part material and the other side of the part material. A mid-surface mesh basically represents the neutral surface of the part. This is the default in starting point VPEs.
 - Larger Area Side: specifies that the mesh should be imposed on the larger-area side of the part material.
 - Smaller Area Side: specifies that the mesh should be imposed on the smaller-area side of the part material.

VPE administrators can customize the default surface for flattening with the site variable **flatteningSurface**.

- Fill Holes in Blanks: applies to FEA flattening only.
 - No: specifies that the mesh (see Surface for Flattening, above) should not be applied to portions of the material surface that will be removed to form a hole. This is the default in starting point VPEs.
 - Yes: specifies that the mesh (see Surface for Flattening, above) should be applied to portions of the material surface that will be removed to form a hole.

VPE administrators can customize the default with the site variable **flatteningFillHoleMethod**.

- Flattening Direction: applies to FEA flattening only.

- aPriori Selected: specifies that the flattening calculation should be based on the ram direction chosen by aPriori. This option is available only in the Sheet Metal—Transfer Die process group, and is the default in starting point VPEs. See [Ram Direction for Transfer Die](#) for more information.
- Average Surface Normal: specifies that the flattening calculation should be based on a ram direction that is the average direction of the normal to the part's surfaces. This is the only option available in the Sheet Metal process group.

VPE administrators for Sheet Metal—Transfer Die can customize the default flattening direction with the site variable **flatteningDirection**.

VPE Administrators also can customize the FEA flattening behavior with the following site variables:

- **flatteningInitialStrainValue** (0.002 by default): for FEA flattening, specifies the strain present in the material before outside forces and loads are applied.
- **flatteningTimeoutSeconds** (600 seconds by default): determines how long FEA flattening will run before timing out; if FEA flattening times out or fails for any reason, an FEA-failure message appears in the Viewer, and geometric flattening is used instead. A value of 0 indicates no timeout—FEA flattening will run indefinitely.

As mentioned above, FEA flattening takes into account material properties, including the following:

- Young's Modulus
- Poisson's Ratio, K (strain-hardening coefficient)
- N (strain-hardening exponent)
- R (Lankford parameter, average).

Materials in starting point VPEs specify these properties. If your VPE includes a material that doesn't specify these properties, aPriori uses the following default values based on material type:

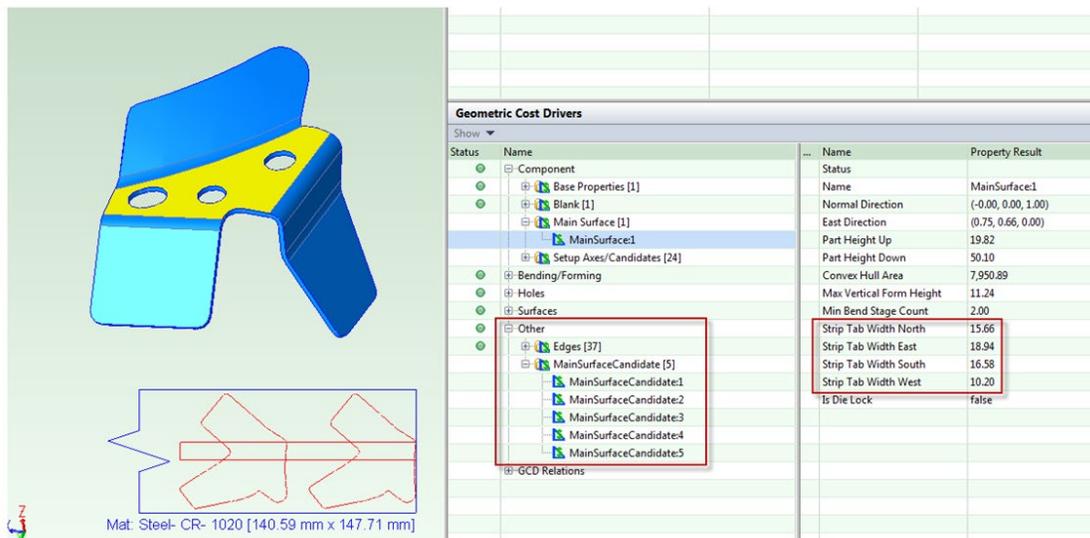
Material Type	Young's Modulus (MPa)	Poisson Ratio	K (strain-hardening coefficient, Mpa)	N (strain-hardening exponent, MPa)	R (Lankford parameter, average)
Aluminum	69000	0.33	341.1	0.21	0.7
Copper	115000	0.33	317	0.54	0.99
Galvanized Steel	207000	0.28	543	0.21	0.99
Stainless Steel	207000	0.28	1426	0.502	1
Steel	207000	0.28	0.28	479.3	1.345

If the material type is not one listed in the table above, the entries for Steel are used.

Main Surface for Hard Tooled Sheet Metal

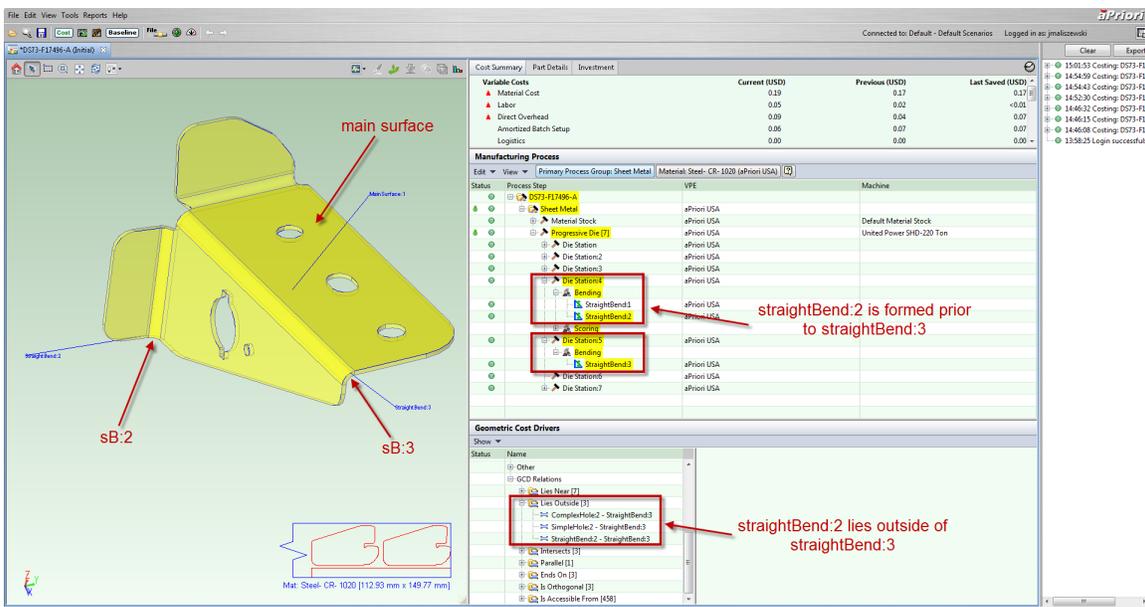
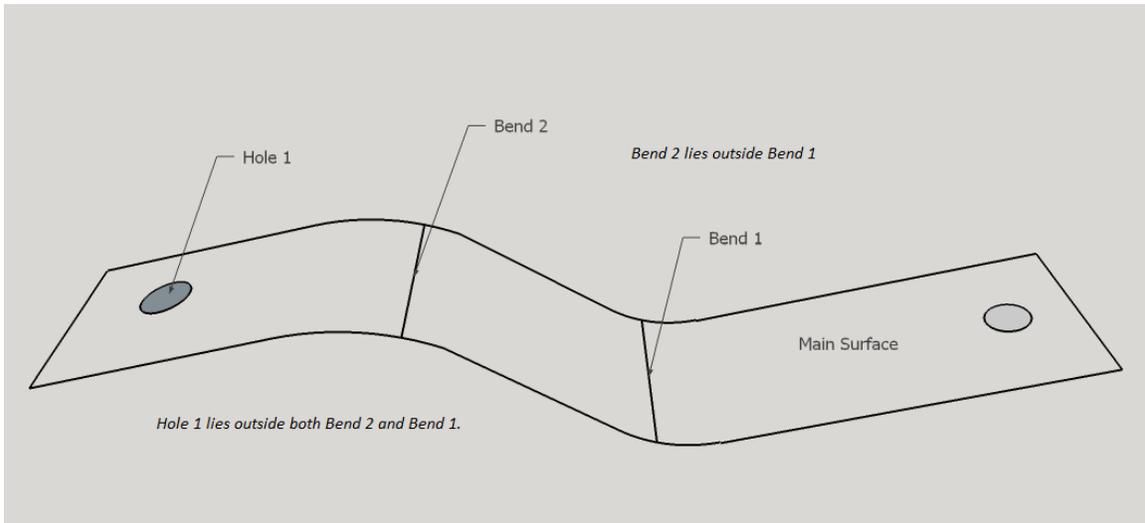
The MainSurface GCD represents a portion of the part that remains parallel to the press table all through the stamping process. Multiple candidates for the main surface are extracted from the part geometry. Final selection of the main surface is carried out by the cost engine. Very roughly, the cost engine selects the largest flat surface on the part. For highly deformed parts, the cost engine looks for the largest surface, ignoring its flatness. For parts with many bends, the cost engine selects a flat surface that minimizes the number of bend stages or stations.

You can modify the cost engine's choice of main surface with the main surface tool, , in the Viewer toolbar. The XY orientation of the surface is determined within the cost model.



LIES_OUTSIDE Relation for Hard Tooled Sheet Metal

Several feasibility, compatibility, and precedence rules refer to the **LIES_OUTSIDE** relation (under **GCD Relations** in the Geometric Cost Drivers pane). If one GCD, *feature-1*, lies between another GCD, *feature-2*, and the main surface, we say that *feature-2* lies outside of *feature-1*, that is, there is a **LIES_OUTSIDE** relation whose value for **First** is *feature-2* and whose value for **Second** is *feature-1*.

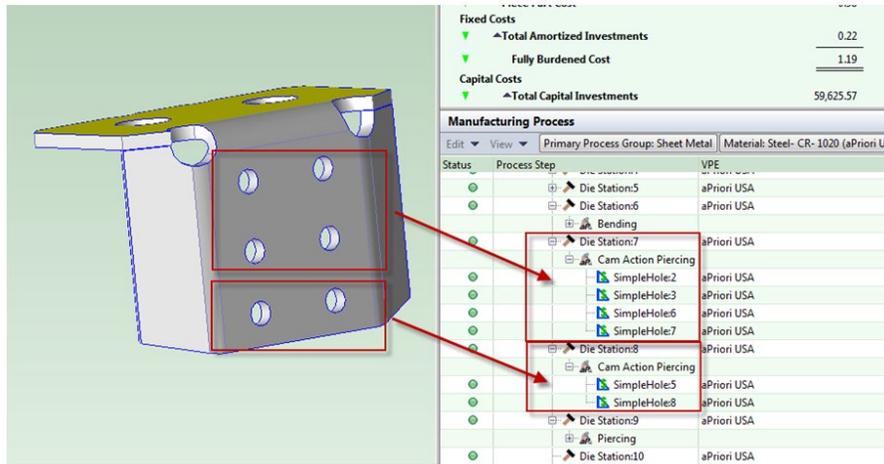


Peninsular Ratio Property for Hard Tooled Sheet Metal

Several feasibility rules depend on the presence or absence of long thin “peninsulas” in Blank GCDs. To detect peninsulas, the cost model determines whether the Blank GCD properties **Worst Peninsular Ratio** and **Worst Peninsular Ratio2** exceed the cost model variables **worstPeninsularRatioThreshold** and **worstPeninsularRatio2Threshold**, respectively.

Cam Bundling for Hard Tooled Sheet Metal

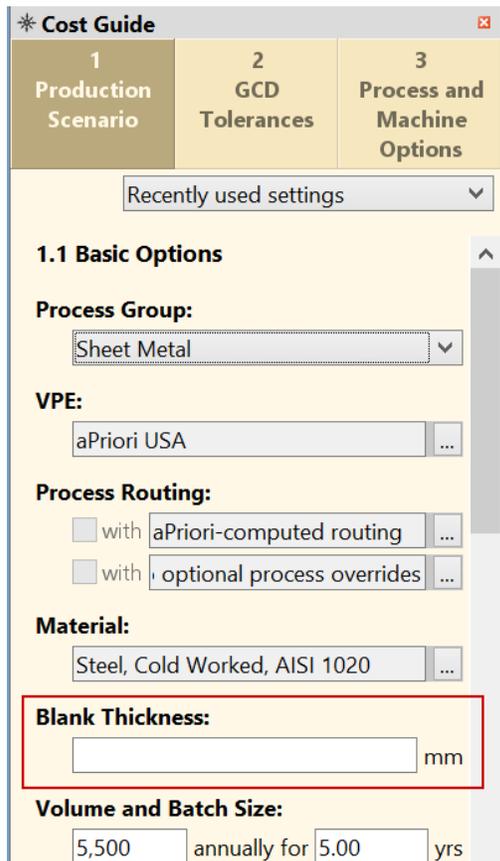
Holes within a threshold distance apart with roughly parallel axes are bundled onto the same Cam Piercing Unit. The bundled holes appear under special Cam Action Piercing GCDs. The cost model variable **holeAxisThreshold** (15 degrees in starting point VPEs) specifies the allowable deviation from parallel.



Surface-only CAD Models for Sheet Metal

In addition to solid CAD models, the Transfer Die and Sheet Metal process groups support surface CAD models, which represent surfaces only, rather than solid geometry. Surface models typically model one side of stamped or soft tooled metal component.

When you use a surface-only model, you must enter the intended part thickness into the **Blank Thickness** field of the Cost Guide. The surface model together with the specified thickness allow aPriori to, in effect, extrapolate a solid model of the part, and then extract geometry and perform costing just as it would with a solid CAD model as input.



You can also specify blank thickness for surface models with the aPriori Bulk Costing interface: right-click on the desired parts (rows) and select **Production Inputs**.

The geometry and costing results for a surface-only model of a part are generally identical or extremely similar to the results for a solid model of the same part. But because information is missing from the surface-only model (even with the addition of a thickness value), some geometric processing might differ slightly.

One type of information that is missing from a surface model is the exact shape produced by the cuts that create the holes and edges of the blank. In these situations, aPriori assumes that the cuts are true, at 90 degrees to the surface.

For example, an elliptical opening in a model (either solid or surface) indicates a hole GCD, but the information in the surface model is not sufficient to determine whether the walls of the hole are cylindrical; so aPriori assumes that the hole is a complex hole (with non-cylindrical walls and an axis perpendicular to the part surface) rather than an angled simple hole (with cylindrical walls and an axis oblique to the part surface). The additional information provided by a thickness value still leaves this under-determined.

Similarly, a surface model lacks sufficient information to determine whether an edge is chamfered.

Note also that the GCD Area and Volume properties for a surface-only model of a part might differ slightly from the same properties for a solid model of the same part. This is because the information in the surface-only model under-determines the effects of bends and curves on volume and surface area calculations. So, in starting point VPEs, costs that depend heavily on surface areas and volumes (for example, costs for heat treatment and surface treatment) might differ slightly between surface-only and solid models.

Note that if you enter a value into the **Blank Thickness** field for a solid CAD model, aPriori ignores it, and issues a message indicating that thickness will be derived from the solid model rather than from the user-entered value. If your company does not use surface-only models, you can remove the **Blank Thickness** field from the Cost Guide if you wish—see the *aPriori System Administration Guide* for information on customizing the Cost Guide.

GCD extraction for surface models can be disabled with the aPriori property `apriori.enable.surface.models.sheetmetal`—see the *aPriori System Administration Guide*.

Routing and Feasibility for Hard Tooled Sheet Metal

This section contains the following subsections:

- Sheet Metal Process Routings
- Operation-level Feasibility and Routing for Progressive Die
- How aPriori Groups Operations onto Die Stations

Sheet Metal Process Routings

By default, aPriori auto-selects the lowest cost routing at the selected facility. You can override the default and select an alternate routing. If the alternate routing is not feasible based on routing rules, aPriori warns you and reverts to auto-selection. If you want to

use the alternate available routing and ignore the routing rules, you can select this option using the Process Routing window. In this case, aPuri attempts to cost the component with the selected routing regardless of feasibility constraints. Note that costing might still fail for other reasons, which would be reported as an error to you, but would not cause aPuri to revert to a different routing.

If the Machining process group has been licensed, Sheet Metal routings can include 3-Axis Milling, Cylindrical Grinding, Gun Drill and 2-axis Wire EDM operations. For complete details about machining, see [Stock Machining and Machining Process Groups](#).

The routing also includes subsequent optional surface treatment and packaging processes, if your company has licensed these modules.

Stage Tooling and Progressive Die process routings that evaluate the type and number of die stages/stations required for a particular component. Operations are determined using die selection algorithms according to individual rules defined for stage tooling dies and progressive die stations respectively. Once die stages and stations have been determined, tooling costs are then computed and displayed.

The default behavior is to let aPuri determine the number of stages. You can also manually edit the number of stages by editing the number of occurrences of the Generic Press (for stage tooling) process or the Die Station component-level operation (for progressive die). A number of setup options also allow you to influence the number of stations for progressive die—see Progressive die process setup.

Partial Progressive Die routings also are supported but not generated automatically by aPuri. Users can construct them from (full) Progressive Die routings by assigning GCDs from Progressive Die to Stage Tooling (generic press), using the GCD Editor.

Note that the cost model relies on a *node occurrence generator* Java plugin (specified by the node attribute `generatorName`) to group operations by die station or stage. See *Working with Zero-or-More Nodes* in the Cost Model Workbench Guide for more information.

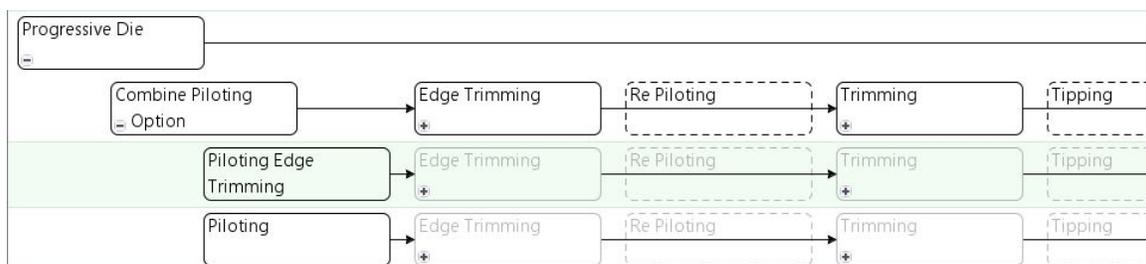
The hard-tooled stamping processes (Stage Tooling, Tandem Press, Progressive Die, and Standard Press) all are available via a separately licensed module.

Operation-level Feasibility and Routing for Progressive Die

Below are the hard-tooled sheet metal operations, grouped by GCD type.

Blank

Initial operations to create the blank consist of piloting or piloting combined with edge trimming, followed by edge trimming, optional repiloting, and additional trimming if necessary.



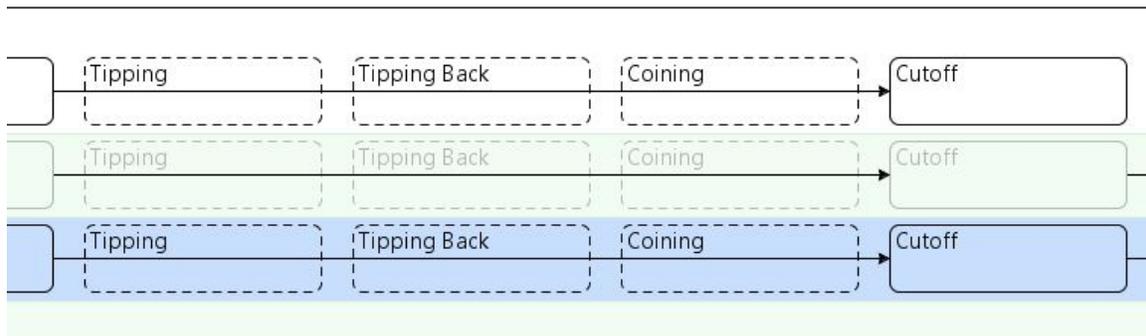
- *Piloting Edge Trimming* is used by default in starting point VPEs. It is used if the setup option **Enable Standalone Piloting Operation** is **No**. This allows piloting and edge trimming to be performed on the same die station.
- *Piloting* is used only if the setup option **Enable Standalone Piloting Operation** is **Yes**. In this case, piloting is performed on a separate die station, prior to edge trimming.
- *Edge Trimming* is used if *at least one* of the following hold:
 - Cost model variable **multipleTrimsProgDie** is **true**. (The variable is set to **true** in aPiori starting point VPEs.)
 - Flattened part has at least one long, thin “peninsula” (see **Peninsular Ratio Property for Hard Tooled Sheet Metal**).

By default, the routing includes one instance of the operation for each edge to be trimmed, except the edge trimmed by the operation *Trimming Piloting*. So the number of instances of this operation is either the value of the cost model variable **numEdgeTrimsPerPart** (if the PSO **Enable Standalone Piloting Operation** is **Yes**) or one less than the value of the cost model variable **numEdgeTrimsPerPart** (if the PSO **Enable Standalone Piloting Operation** is **No**). In starting point VPEs, the cost model variable **numEdgeTrimsPerPart** is 1.

- *Re Piloting* must be manually included in a routing, and is always considered feasible.
- *Trimming* is included in the operation sequence only if *at least one* of the following hold:
 - Cost model variable **multipleTrimsProgDie** is **true**. (The variable is set to **true** in aPiori starting point VPEs.)
 - Flattened part has at least one long, thin “peninsula” (see **Peninsular Ratio Property for Hard Tooled Sheet Metal**).

By default, the routing includes one instance of the *Trimming* operation for each trim still to be performed. aPiori calculates the number of trims based on the blank perimeter and **numEdgeTrimsPerPart** (1 in starting point VPEs). This value is limited by the cost model variable **maxTrimStagesProgDie** (4 in starting point VPEs); in other words, the number of *Trimming* instances never exceeds **maxTrimStagesProgDie** minus **numEdgeTrimsPerPart**. You can override the calculated value with the PSO **Direct Trim Angle Threshold**.

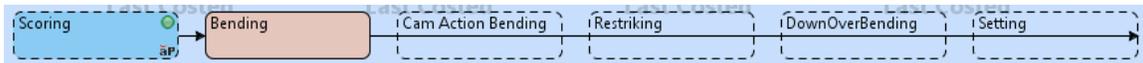
Later operations on the blank consist of optional operations tipping, tipping back, and coining, followed by cutoff.



- *Tipping* must be manually included in a routing, and is always considered feasible.
- *TippingBack* must be manually included in a routing, and is always considered feasible.
- *Coining* is included in the operation sequence only if the blank is chamfered (see the Blank property **Is Chamfered** in the Geometric Cost Drivers pane).
- *Cutoff* is always included.

StraightBend

StraightBends are created with the Bending operation and several optional operations. In the following example sequence, aPriori decided to include Scoring:



- *Scoring* is performed if *both* the following hold:
 - Process setup option **Enable SCORING Operation** is **Yes**. (The PSO default is **No** is starting point VPEs.)
 - Bend is a long hem or bend is close to a large hole.

Long hem recognition compares the bend arc angle with the plant variables **maxHemRecognitionAngle** and **minHemRecognitionAngle**, and compares the bend length with the plant variable **hemLengthThreshold**.

Close means a distance less than the product of blank thickness and the plant variable **formBasedScoringMultiplierThreshold**.

Large hole recognition compares diameter with **minSimpleHoleDiameterThreshold** (for simple holes) and perimeter with **minComplexHolePerimeterThreshold** (for complex holes).
- *Bending* is feasible only if *both* the following hold:
 - Bend arc angle is greater than or equal to the cost model variable **flapBasedRecognitionAngle**.
 - Bend flap size greater than or equal to the cost model variable **bendFlapSizeThreshold**.
- *Cam Action Bending* is performed if *both* the following hold:
 - Bend arc angle is greater than or equal to the cost model variable **camBendingRecognitionAngle**.
 - Bend is not a standard hem. Standard hem recognition compares the bend arc angle with the plant variables **maxHemRecognitionAngle** and **minHemRecognitionAngle**, and requires that the hem is not between the main surface and any other bend or form.
- *Restriking* is performed if both the following hold:
 - Setup option **Enable Restriking Operation for Straight and Curved Bends** is set to **Yes** (the default in starting point VPEs).
 - Bend flap size greater than or equal to the cost model variable **bendFlapSizeRestrikeThreshold**.
- *DownOverBending* is performed if the following condition holds:
 - Bend is a standard hem. Standard hem recognition requires that the bend arc angle is between the plant variables **maxHemRecognitionAngle** and

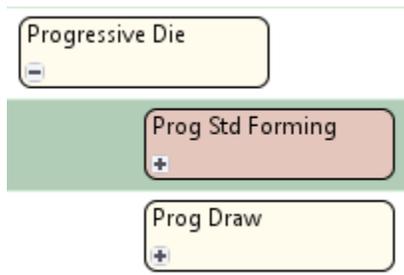
minHemRecognitionAngle, and requires that the hem is not between the main surface and any other bend or form.

- **Setting** is performed if the following condition holds:
 - Bend is a standard hem. Standard hem recognition requires that the bend arc angle is between the plant variables **maxHemRecognitionAngle** and **minHemRecognitionAngle**, and requires that the hem is not between the main surface and any other bend or form.

Form

Forming operations are divided into two categories:

- Standard forming
- Drawing



Standard forming operations are used only if *both* the following hold:

- *At least one* of the following holds:
 - Deep draw ratio is less than the cost model variable **deepDrawRatioThreshold**. The deep draw ratio is the ratio of the form's depth to **Width** (depth is either **Depth Up** or **Depth Down**, whichever is greater):

$$\max(\text{Depth Up}, \text{Depth Down}) / \text{SER Width} < \text{deepDrawRatioThreshold}$$
 - Form's enclosing-rectangle area (product of **SER Length** and **SER Width**) is more than half of the part's area (product of component **Length** and **Width**):

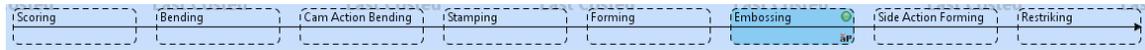
$$(\text{form SER Length} * \text{form SER Width}) / (\text{component Length} * \text{component Width}) > 0.5$$
 - Form **Sub Type** is **CurvedBend**.
 - Form **Sub Type** is **Stamp**.
 - *At least one* of the following holds:
 - Form is not too deep; that is, the sum of the form's **Depth Up** and **Depth Down** is less than the cost model variable **drawDepthThreshold**:

$$\text{Depth Up} + \text{Depth Down} < \text{drawDepthThreshold}$$
 - Draw ratio is less than the cost model variable **drawRatioThreshold**. The draw ratio is the **GCD Area** divided by the part's area (product of component **Length** and **Width**):

$$\text{Form Area} / (\text{Component Length} * \text{Component Width}) < \text{drawRatioThreshold}$$
 - Form's enclosing-rectangle area (product of **SER Length** and **SER Width**) is more than half of the part's area (product of component **Length** and **Width**).

$$(\text{form SER Length} * \text{form SER Width}) / (\text{component Length} * \text{component Width}) > 0.5$$
 - Form **Sub Type** is **CurvedBend**.
 - Form **Sub Type** is **Stamp**.

Standard forming operations are all optional. In the following example sequence, aPuri decided to include Embossing:



- **Scoring** is performed only if *both* the following hold:
 - Cost model variable **scoreBendsProgDie** is **true**.
 - Bend is a long hem or bend is close to a large hole.

Long hem recognition compares the bend arc angle with the plant variables **maxHemRecognitionAngle** and **minHemRecognitionAngle**, and compares the bend length with the plant variable **hemLengthThreshold**.

Close means a distance less than the product of blank thickness and the plant variable **formBasedScoringMultiplierThreshold**.

Large hole recognition compares diameter with **minSimpleHoleDiameterThreshold** (for simple holes) and perimeter with **minComplexHolePerimeterThreshold** (for complex holes).
- **Bending** is performed only if the form **Sub Type** is **CurvedBend**.
- **Cam Action Bending** is performed only if *all* the following hold:
 - Form **Sub Type** is **CurvedBend**.
 - Bend arc angle is greater than or equal to the cost model variable **camBendingRecognitionAngle**.
 - Bend is not a standard hem. Standard hem recognition compares the bend arc angle with the plant variables **maxHemRecognitionAngle** and **minHemRecognitionAngle**, and requires that the hem is not between the main surface and any other bend or form.
- **Stamping** is performed only if the form **Sub Type** is **Stamp**
- **Forming** is performed only if *one* of the following holds:
 - Form **Sub Type** is **Tab**.
 - Form **Sub Type** is **Bridge**
 - Form **Sub Type** is **Emboss** and form is a dimple. Dimple recognition compares form perimeter with the cost model variable **maxDimplePerimeter**, and compares each of depth up and depth down with the cost model variable **maxDimpleDepth**.
- **Embossing** is included in the operation sequence only if *all* of the following hold:
 - Form **Sub Type** is **Emboss**.
 - Form is not a dimple. Dimple recognition compares form perimeter with the cost model variable **maxDimplePerimeter**, and compares each of depth up and depth down with the cost model variable **maxDimpleDepth**.
 - Form either is orthogonal to the main surface or is both relatively large and not on the edge of either the part or a complex hole.

A form is orthogonal to the main surface if it is accessible from a direction that forms an angle with the main surface of about 90 degrees. The angle must be within **sideActionAxisTolerance** of 90 degrees to be considered orthogonal.

A form is considered relatively large if the cost model variable **formAreaAreaThreshold** is less than the percentage of half the component **Surface Area** occupied by the form **Area**, that is, if $\text{formAreaThreshold} < (\text{form Area} / (\text{component Surface Area} / 2)) * 100$.
- **Side Action Forming** is included in the operation sequence only if *all* of the following hold:

- Form **Sub Type** is **Emboss**.
- Form is not orthogonal to the main surface. A form is orthogonal to the main surface if it is accessible from a direction that forms an angle with the main surface of about 90 degrees. The angle must be within **sideActionAxisTolerance** of 90 degrees to be considered orthogonal.
- Form is highly deformed. A form is considered highly deformed if the cost model variable **deformationThreshold** is less than the percentage of half the component **Surface Area** occupied by the forms child GCDs:

$\text{deformationThreshold} < (\text{sum of Areas of form's children} / (\text{component Surface Area} / 2)) * 100.$

- Form is either on the edge of the part or on the edge of a complex hole.
- Form is relatively small. A form is considered relatively small if the cost model variable **formAreaThreshold** is greater than the percentage of half the component **Surface Area** occupied by the form **Area**:

$\text{formAreaThreshold} > (\text{form Area} / (\text{component Surface Area} / 2)) * 100.$

- **Restriking** is included in the operation sequence only if the setup option **Enable Restriking Operation for Straight and Curved Bends** is set to **Yes** (the default in starting point VPEs) and *at least one* of the of the following holds:
 - Form is orthogonal to the main surface. A form is orthogonal to the main surface if it is accessible from a direction that forms an angle with main surface of about 90 degrees. The angle must be within **sideActionAxisTolerance** of 90 degrees to be considered orthogonal.
 - Form is not on the edge of either the part or a complex hole.
 - Form is relatively large. A form is considered relatively large if the cost model variable **formAreaAreaThreshold** is less than the percentage of half the component **Surface Area** occupied by the form **Area**.

$\text{formAreaThreshold} < (\text{form Area} / (\text{component Surface Area} / 2)) * 100.$

- Form **Sub Type** is not **Emboss**.

In addition, if the form's **Sub Type** is **Curved Bend**, the following must hold for this operation to be included in the sequence:

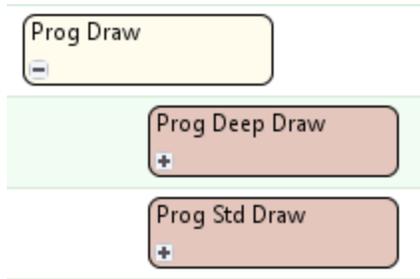
- Form's **Depth up** or **Depth Down** (whichever is larger) is less than or equal to the cost model variable **bendFlapSizeRestrikeThreshold**.

In addition, if the form's **Sub Type** is *not* **Curved Bend**, *one* of the following must hold

- Form **Sub Type** is **Emboss** and form is sufficiently big. A form is considered sufficiently big if the sum of its **Depth Up** and **Depth Down** is greater than 10mm and the form is not a deep dimple. Deep dimple recognition compares form perimeter with the cost model variable **maxDimplePerimeter**, and compares each of depth up and depth down with the cost model variable **maxDeepDimpleDepth**.
- Form **Sub Type** is **Bridge** and form is sufficiently deep. A form is considered sufficiently deep if the form's **Depth Up** or **Depth Down** (whichever is greater) is greater than the product of the blank **Thickness** and the cost model variable **bridgeRestrikingMultiplier**.

Drawing operations are divided into two categories:

- Deep drawing
- Standard drawing



- Deep Drawing is feasible only if both the following hold:
 - Form's deep draw ratio is greater than or equal to the cost model variable **deepDrawRatioThreshold**. The deep draw ratio is the ratio of the form's depth to width, that is, the form's **Depth Up** or **Depth Down** (whichever is larger) divided by the form's **SER Width**.
 - Form's enclosing-rectangle area (product of **SER Length** and **SER Width**) is less than or equal to half the part's area (product of component **Length** and **Width**).
$$(\text{form SER Length} * \text{form SER Width}) / (\text{component Length} * \text{component Width}) \leq 0.5$$

This operation is performed only if the form's **Sub Type** is not **Stamp**.

The operation, if performed, is performed between 2 and **maxNumberDeepDraws** (cost model variable) times. The number of times is the form's deep draw ratio divided by the cost model variable **deepDrawRatioThreshold**, if within range:

of times = $\text{rounddown}(((\text{max}(\text{Depth Up}, \text{Depth Down}) / \text{SER Width}) / \text{deepDrawRatioThreshold}))$

If this value is less than 2, the operation is performed twice. If this value is greater than **maxNumberDeepDraws**, the operation is performed **maxNumberDeepDraws** times.

- Standard Drawing is performed only if the form's **Sub Type** is not **Stamp**.

The operation, if performed, is performed between 2 and **maxNumberDraws** (cost model variable) times. The number of times is the form's draw ratio divided by the cost model variable **drawRatioThreshold**, if within range:

of times = $\text{rounddown}(((\text{Depth Up} + \text{Depth Down}) / \text{SER Width}) / \text{drawRatioThreshold}))$

If this value is less than 2, the operation is performed twice. If this value is greater than **maxNumberDraws**, the operation is performed **maxNumberDraws** times.

SimpleHole

Simple hole operations are all optional. In the following example sequence, aPiori decided to include Piercing and CounterSinking:



- Piercing is feasible only if both the following hold:
 - Hole is not blind.
 - Operation is capable of achieving the required tolerance (to view the achievable tolerance range, see the Piercing process setup option **Best/Worst Achievable Tolerance**).

Piercing is included in the operation sequence only if at least one of the following holds:

- Hole is approximately orthogonal to the main surface.
- Setup option **Pierce Before or After Forms** is set to **holesBeforeForms**.

- Hole is flanged.
- Hole is countersunk.
- Hole is threaded.
- Hole is not accessible from any candidate setup axis.
- Cam Action Piercing is feasible only if all the following hold:
 - Hole is not approximately orthogonal to the main surface.
 - Hole is not flanged.
 - Hole is not countersunk.
 - Hole is not threaded.
 - Hole is accessible from a candidate setup axis.
 - Setup option **Pierce Before or After Forms** is set to **holesAfterForms**.
- Extruding is included in the operation sequence only if the following holds:
 - Hole is flanged.
- Coining is included in the operation sequence only if all the following hold:
 - PSO **Enable COINING Operations for SimpleHoles** is set to **Yes**.
 - Hole is flanged.
 - Hole is threaded.
- Shaving is included in the operation sequence only if all the following hold:
 - PSO **Enable SHAVING Operatoins for SimpleHoles** is set to **Yes**.
 - Hole is flanged.
 - Hole is threaded.
- Countersinking is included in the operation sequence only if the following holds:
 - Hole is countersunk.
- Tapping is included in the operation sequence only if all the following hold:
 - In-die tapping is enabled; that is the PSO **Enable In Die TAPPING operations** is **Yes** (the default in starting point VPEs).
 - Hole is threaded; that is, the **isThreaded** property of the GCD is **true**.
 - Hole diameter is within range; that is, the diameter is between sizes M2 and M12 (1.78mm and 11.51 mm in starting point VPEs; specified in the lookup table **toolingComponentAttributes**, in the entries for **holeDiameterM2** and **holeDiameterM12**).

ComplexHole

Complex hole operations are required and feasible under the circumstances described below.

- Cam Piercing is required only if all the following hold:
 - Hole is not approximately orthogonal to the main surface.
 - Hole is not flanged.
 - Hole is not coined.
 - Hole is accessible from a candidate setup axis.
 - Setup option **Pierce Before or After Forms** is set to **holesAfterForms**.

It is feasible only if the operation is capable of achieving the required tolerance.
- Coining is required if the hole is chamfered. It is feasible only if the operation is capable of achieving the required tolerance.

- Extruding is required if the hole is flanged. It is feasible only if the operation is capable of achieving the required tolerance.
- Piercing is required only if at least one of the following holds:
 - Hole is not approximately orthogonal to the main surface.
 - Setup option **Pierce Before or After Forms** is set to **holesBeforeForms**.
 - Hole is flanged.
 - Hole is chamfered.
 - Hole is not accessible from any candidate setup axis.

It is feasible only if the operation is capable of achieving the required tolerance.

- Trimming is required only if both the following hold:
 - Hole is sufficiently large, that is, the hole's **Perimeter** is greater than or equal to the cost model variable **bigEnoughArtifactPerimeter**: **Perimeter** > = **bigEnoughArtifactPerimeter**
 - Hole intersects, but is not coplanar with, a sufficiently large multibend or form of **Sub Type Emboss** that has no bends between it and the main surface. A form is sufficiently large if it is not a dimple and the sum of **Depth Up** and **Depth Down** is greater than 25 mm. Dimple recognition compares form perimeter with the cost model variable **maxDimplePerimeter**, and compares each of depth up and depth down with the cost model variable **maxDimpleDepth**.

It is feasible only if the operation is capable of achieving the required tolerance.

How aPriori Groups Operations onto Die Stations

The Progressive Die operation routings for a part determine the order of operations on a given GCD. All together, they provide a partial ordering of all the operations on all the part's GCDs—only operations on the same GCD are ordered with respect to one another. aPriori further orders the operations on all GCDs by assigning operations to die stations, and ordering the die stations. (Operations assigned to the same die station are not ordered with respect to one another; they are performed at the same time on different GCDs.)

Three kinds of rules guide aPriori's assignment of operations and ordering of die stations:

- Compatibility Rules
- Precedence Rules
- Idle Station Rules

Compatibility Rules

Any two operations that are assigned to the same die station must be compatible with one another. Two operations are compatible if and only if they *not* incompatible, as defined below:

- Any Trimming operation is incompatible with any Edge Trimming operation.
- Two Trimming operations are incompatible if they are not both performed on complex holes.
- Any two Edge Trimming operations are incompatible.
- Any two Post Form Trimming operations are incompatible.
- Any two Cam Action Trimming operations are incompatible.

- A Cam Action Bending operation is incompatible with any operation.
- A Tipping operation is incompatible with any operation that is not another Tipping operation.
- A Tipping Back operation is incompatible with any operation that is not another Tipping Back operation.
- A Cam Piercing operation is incompatible with any other Cam Piercing operation that is performed by a different Cam unit.
- Any Cam Piercing operation is incompatible with any Restriking operation.
- Any two operations which work primarily in opposite directions are incompatible, where the direction in which an operation works is defined (in terms of properties of the GCD on which the operation is performed) as follows:
 - Coining: **Chamfer Direction**
 - Countersinking, countersink direction
 - Extruding, flange direction
 - Cam over bending, bend direction
 - Down over bending, bend direction
 - Cam Action Bending on a Straight bend, bend direction
 - Embossing, direction of greater depth (for example, up, if **Depth UP** is greater than **Depth Down**)
 - Shear Embossing, direction of greater depth
 - A Bending operation on a Form GCD, direction of greater depth
 - Any operation on a MultiBend GCD, bend direction
 - A Bending operation on a Straight Bend GCD, bend direction
 - Gussett Bending, bend direction
- Any Piercing operation is incompatible with any operation of one of the following kinds:
 - Restriking
 - Forming
 - Deep Drawing
 - Drawing
 - Embossing
 - Coining
 - Bending
 - Down Over Bending
 - Side Action Forming
 - Scoring
- Two Piercing operations are incompatible if the GCDs on which they are performed are too close to each other, that is, if the distance between them (according to the LIES_NEAR relation) is less than or equal to the product of the blank's **Thickness** and the cost model variable **minHoleSpacingMultiplier**.
- Two bending operations are incompatible if one bend lies between the other bend and the part's main surface.
- A Bending operation on a GCD is incompatible with a Restriking operation on another GCD, if one GCD lies between the other GCD and the main surface.

- A Bending operation on a GCD is incompatible with a Cam Piercing operation on another GCD, if one GCD lies between the other GCD and the main surface.
- Any Tapping operation is incompatible with any non-Tapping operation.
- Two Tapping operations are incompatible if the GCDs on which they are performed are too close to each other, that is, if the distance between them (according to the LIES_NEAR relation) is less than the cost model variable **minimumTapSpacingDistance**.
- Any two Side Action Forming operations are incompatible.

If two operations are not incompatible as defined above, they are compatible.

Precedence Rules

The precedence rules specify, for any pair of operations, whether one must be performed before the other and, if so, which must be first.

If one operation must precede another, according to these rules, the first operation must be assigned to a die station that is earlier than the die station to which the second operation is assigned.

Following are the precedence rules:

- An Extrusion, Coining, Countersinking, Piercing, or Tapping operation must precede a bending operation of any of the following types, if the bend is between the extrusion or hole and the part's main surface, and the extrusion or hole is not orthogonal to the main surface (that is, it is not accessible from a direction that is within 15 degrees of forming a 90 degree angle with the main surface):
 - Any operation on a MultiBend GCD.
 - Bending
 - Restriking
 - Setting
 - Scoring
 - Down Over Bending
 - Cam Action Bending
- An Embossing operation must precede a bending operation of any of the following types, if the bend is between the form and the main surface:
 - Any operation on a MultiBend GCD.
 - Bending
 - Gussett Bending
 - Cam Over Bending
 - Down Over Bending
 - Cam Action Bending
 - Setting
 - Scoring
- A Bending operation on a GCD, bend1, must precede a Bending operation on a GCD, bend2, if bend2 is between bend1 and the main surface.

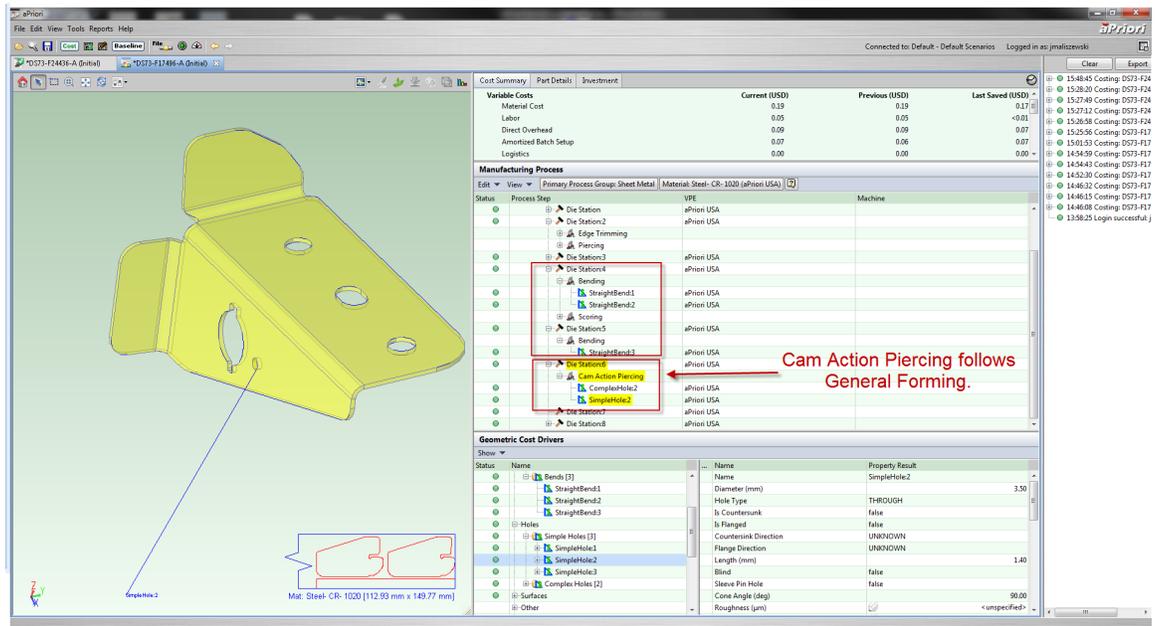
The screenshot displays the aPTe software interface for sheet metal cost modeling. On the left, a 3D model of a yellow sheet metal part is shown with labels for 'main surface', 'sb:2', and 'sb:3'. The central 'Manufacturing Process' table details the sequence of operations: 'Sheet Metal' (Machine: VPE), 'Material Stock' (Machine: Default Material Stock), 'Progressive Die' (Machine: United Power 34D-220 Ton), and three 'Bending' operations (StraightBend1, StraightBend2, StraightBend3) performed at 'Die Station1', 'Die Station2', and 'Die Station3' respectively. Red boxes and arrows indicate that StraightBend2 is formed prior to StraightBend3 and lies outside of it. The 'Geometric Cost Drivers' table at the bottom lists features such as 'SimpleHole2 - StraightBend3' and 'StraightBend2 - StraightBend3'.

- A Bending operation must precede a Cam Piercing operation, if the bend is between the pierce and the main surface.
- A Cam Action Bending operation on a GCD, *bend1*, must precede a Bending operation on a GCD, *bend2*, if *bend2* is between *bend1* and the main surface.
- A Cam Action Bending operation on a GCD, feature1, must precede a Restriking operation on a GCD, feature2, if feature2 is between feature1 and the main surface.
- The Cutoff operation must be preceded by every other operation.
- The Piloting operation must precede every other operation.
- The Piloting Edge Trimming operation must precede any other operation except an edge trimming operation.
- Any operation of one of the following types must precede any Repiloting operation:
 - Embossing
 - Restriking
 - Drawing
 - Deep Drawing
- Any Embossing operation must precede any Restriking operation.
- Any Edge Trimming operation must precede any operation of one of the following types:
 - Cam Piercing
 - Embossing
 - Bending
 - Drawing
 - Deep Drawing
- Any Full Blanking operation must precede any operation of one of the following types:
 - Embossing
 - Bending

- Drawing
- Deep Drawing
- Cam Piercing
- Shear Embossing
- Operation on a MultiBend GCD
- Gusset Bending
- Cam Over Bending
- Down Over Bending
- Setting
- Scoring
- Cam Action Bending
- Stamping
- Forming
- Shear Forming
- Shear Stamping
- Restriking
- Extruding
- Coining
- Countersinking
- Side Action Forming
- Any Trimming operation must precede any operation of one of the following types:
 - Bending
 - Cam Piercing
 - Embossing
 - Shear Embossing
 - Operation on a MultiBend GCD
 - Gusset Bending
 - Cam Over Bending
 - Down Over Bending
 - Setting
 - Scoring
 - Cam Action Bending
 - Stamping
 - Forming
 - Shear Forming
 - Shear Stamping
 - Restriking
 - Extruding
 - Coining
 - Countersinking
 - Side Action Forming

- Drawing
- Deep Drawing
- Any operation of one of the following types must precede any Cam Action Piercing operation:
 - Side Action Forming
 - Cam Action Bending
 - Down Over Bending
 - Countersinking
 - Restriking
- Any Bending operation must precede any Restriking operation.
- Any operation of one of the following types on a GCD, *feature1*, must precede any Cam Action Bending operation on a given bend, if *feature1* does not lie between the bend and the main surface:
 - Operation on a MultiBend GCD
 - Setting
 - Scoring
 - Stamping
 - Forming
 - Drawing
 - Deep Drawing
 - Embossing
 - Restriking
 - Coining
 - Bending
 - ShearEmbossing
 - ShearForming
 - ShearStamping
- Any operation of one of the following types must precede any Cam Action Piercing operation:
 - Operation on a MultiBend GCD
 - Setting
 - Scoring
 - Stamping
 - Forming
 - Drawing
 - Deep Drawing
 - Embossing
 - Restriking
 - Coining
 - Bending
 - ShearEmbossing
 - ShearForming
 - ShearStamping

The screen capture below shows Bending operations preceding a Cam Action Piercing operation.



- Any operation of one of the following types must precede any Cam Trimming operation:
 - Operation on a MultiBend GCD
 - Setting
 - Scoring
 - Stamping
 - Forming
 - Drawing
 - Deep Drawing
 - Embossing
 - Restriking
 - Coining
 - Bending
 - ShearEmbossing
 - ShearForming
 - ShearStamping
- A Piercing operation on a hole must precede a Bending operation, if the hole is not accessible from any candidate setup axis.
- A Cam Action Piercing operation on must precede a Piercing operation on a given hole if the setup option **Pierce Before or After Forms** is set to **holesAfterForms** and the hole is accessible from a direction that is within 15 degrees of the perpendicular to the main surface.
- Any operation of one of the following types must precede a Piercing operation on a given hole if the setup option **Pierce Before or After Forms** is set to **holesAfterForms** and the hole is accessible from a direction that is within 15 degrees of the perpendicular to the main surface:

- Forming
- Deep Drawing
- Drawing
- Embossing
- Restriking
- Coining
- Setting
- Stamping
- Side Action Forming
- Cam Action Bending
- DownOverBending
- Bending
- An orthogonal hole-making operation (Piercing, Extruding, Coining, Shaving, CounterSinking, or Tapping) must precede an operation of one of the following types on a given hole if the setup option **Pierce Before or After Forms** is set to **holesBeforeForms**:
 - Forming
 - Deep Drawing
 - Drawing
 - Embossing
 - Restriking
 - Coining
 - Setting
 - Stamping
 - Side Action Forming
 - Cam Action Bending
 - DownOverBending
 - Bending
- Any Post Form Trimming operation must precede any Piercing operation.
- Any Post Form Trimming operation must precede any Cam Action Piercing operation.
- Any Cam Action Trimming operation must precede any Piercing operation.
- Any Cam Action Trimming operation must precede any Cam Action Piercing operation.
- Any operation of one of the following types must precede any Cam Action Trimming operation:
 - Forming
 - Deep Drawing
 - Drawing
 - Embossing
 - Coining
 - Bending
 - DownOverBending

- Side Action Forming
- Scoring
- Bending
- Cam Action Bending
- Any Embossing operation must precede any Tapping operation.
- Any Cam Piercing operation must precede any Tapping operation on a hole that is orthogonal to the main surface if the setup option **Pierce Before or After Forms** is set to **holesAfterForms**.
- Any operation of one of the following types must precede and Post Form Trimming operation:
 - Embossing
 - Restriking
 - Drawing
 - DeepDrawing
 - Bending
 - CamActionBending

Idle Station Rules

aPriori sometimes adds idle stations before or after a given station, based on the following rules:

- Tapping: an idle station must precede a station that includes a Tapping operation, by default in aPriori starting point VPEs.
 VPE administrators can customize the default with the cost model variable **addIdleBeforeAfterTappingEnabled** (which is set to **Before and After** in aPriori Starting Point VPEs).
 You can override the default on a per-part basis with the PSO [Add Idle Station Before After Tapping](#).
- Cutoff: an idle station must precede a station that includes a Cutoff operation, by default in aPriori starting point VPEs.
 VPE administrators can customize the default with the cost model variable **addIdleBeforeCutoffEnabled** (which is set to **Yes** in aPriori Starting Point VPEs).
 You can override the default on a per-part basis with the PSO [Add IDLE Station Before CUTOFF Station](#).
- Tapping: an idle station must follow a station that includes a Tapping operation, by default in aPriori starting point VPEs.
 VPE administrators can customize the default with the cost model variable **addIdleBeforeAfterTappingEnabled** (which is set to **Before and After** in aPriori Starting Point VPEs).
 You can override the default on a per-part basis with the PSO [Add Idle Station Before After Tapping](#).
- Trimming: an idle station must follow a station that includes a Trimming operation, by default in starting point VPEs, if the blank pitch (see [Blank Pitch](#)) is less than 80mm.

VPE administrators can use the cost model variable **defaultBlankPitchThreshold** to customize the blank pitch that, by default, requires an idle station. VPE administrators can use the cost model variable **addIdleAfterTrimmingEnabled** to specify that, by default, trimming requires no idle station, regardless of blank pitch.

You can override the defaults on a per-part basis with the PSOs [Add Idle Station After Trimming](#) and [Add IDLE Station Following TRIMMING Station if Blank Pitch is Less Than This](#).

- **Cam Action Piercing:** an idle station must follow a station that includes a Cam Action Piercing operation, by default in aPriori starting point VPEs, if the cam approach is within 45° of being parallel to the part strip flow.

VPE administrators can use the cost model variable **camApproachAngleThreshold** to customize the default allowable deviation from parallel for cam unit approach. VPE administrators can use the cost model variable **addIdleAfterCamPierceEnabled** to specify that, by default, cam piercing requires no idle station, regardless of the cam's angle of approach.

You can override the default on a per-part basis with the PSO [Add Idle Station After Cam Piercing](#).

- **Cam Action Bending:** an idle station must follow a station that includes a Cam Action Bending operation, by default in aPriori starting point VPEs, if the cam approach is within 45° of being parallel to the part strip flow.

VPE administrators can use the cost model variable **camApproachAngleThreshold** to customize the default allowable deviation from parallel for cam unit approach. VPE administrators can use the cost model variable **addIdleAfterCamBendEnabled** to specify that, by default, cam bending requires no idle station, regardless of the cam's angle of approach.

You can override the default on a per-part basis with the PSO [Add Idle Station After Cam Bending](#).

- **Cam Action Trimming:** an idle station must follow a station that includes a Cam Action Trimming operation, by default in aPriori starting point VPEs, if the cam approach is within 45° of being parallel to the part strip flow.

VPE administrators can use the cost model variable **camApproachAngleThreshold** to customize the default allowable deviation from parallel for cam unit approach. VPE administrators can use the cost model variable **addIdleAfterCamTrimEnabled** to specify that, by default, cam piercing requires no idle station, regardless of the cam's angle of approach.

You can override the default on a per-part basis with the PSO [Add Idle Station After Cam Trimming](#).

- **Cam Action Forming:** an idle station must follow a station that includes a Cam Action Forming operation, by default in aPriori starting point VPEs, if the cam approach is within 45° of being parallel to the part strip flow.

VPE administrators can use the cost model variable **camApproachAngleThreshold** to customize the default allowable deviation from parallel for cam unit approach. VPE administrators can use the cost model variable **addIdleAfterCamFormEnabled** to specify that, by default, cam piercing requires no idle station, regardless of the cam's angle of approach.

You can override the default on a per-part basis with the PSO Add Idle Station After Cam Forming.

User Inputs for Hard Tooled Sheet Metal

This section has the following subsections:

- Progressive die process setup
- Tandem Die Process Setup

See also Top-level Process Setup Options.

Progressive die process setup

This section covers progressive die setup options.

The following options control the addition of extra space (for various purposes) around the part's flattened pattern, between patterns, and between patterns and the coil edge:

- **Press Carrier Strip Type:** controls type and number of carrier strips.
- **Single Edge Carrier Strip Width:** adds material for carrier strip.
- **Double Edge Carrier Strip Width:** adds material for carrier strips.
- **Press French Stop:** adds space for a French stop.
- **Width of Addendum Added to Blank Size [per side]:** adds material for holding during stamping (or compensates for underestimation of flattened-part size).
- **Edge Margin Width and Part Spacing Width:** add space for cutting a part without damaging adjacent parts.
- **Trim Strip Length for Center Carrier Strip Type:** adds space for pilot holes in a center-type carrier strip.
- **Maximum Strip Width:** constrains the feasible strip widths.
- **Minimum Strip Width:** constrains the feasible strip widths.

The following options control the layout and orientation of blanks:

- **Number of Parts Stamped Concurrently**
- **Blank XY Orientation within Part Strip**

The following options each control both blank orientation and extra space:

- **Blank Pitch**
- **Coil Width**

The following options affect the number of die stations:

- **Pierce Before or After Forms**
- **Add IDLE Station Before CUTOFF Station**
- **Add IDLE Station Following TRIMMING Station if Blank Pitch is Less Than This**
- **Enable SCORING Operations for Bends**
- **Enable COINING Operations for SimpleHoles**
- **Enable SHAVING Operations for SimpleHoles**
- **Enable Restriking Operation for Straight and Curved Bends**
- **Enable Standalone Piloting Operation**

- Set Number of Trimming Operations
- Enable In Die TAPPING operations
- Add Idle Station Before After Tapping
- Add Idle Station After Trimming
- Add Idle Station After Cam Forming
- Add Idle Station After Cam Trimming
- Add Idle Station After Cam Bending
- Add Idle Station After Cam Piercing

A number of additional options are also provided—see below.

Number of Parts Stamped Concurrently

Specifies whether two parts can be stamped concurrently, and if so, whether the two are flipped or rotated with respect to one another. Select one of the following options:

- Evaluate Strip Nesting Layout: 1 Out (default)
- Evaluate Strip Nesting Layout: 2 Out, Mirrored
- Evaluate Strip Nesting Layout: 2 Out, Rotated

Blank XY Orientation within Part Strip

In True-Part Nesting mode (see [Material Utilization and Part Nesting for Hard Tooled Sheet Metal](#)), specifies how aPriori will determine the blank's angle within the part strip. The first two options attempt to find the angle that optimizes material utilization; the third option allows the user to specify the angle explicitly. Select one of the following options:

- **Determine Angle optimizing utilization, using default increment:** specifies the part rotations aPriori considers in order to optimize nesting. aPriori considers non-negative, whole number multiples of **defaultIncrementAmount** that are less than 360 degrees. **defaultIncrementAmount** is a cost model variable that is set to 5 in aPriori starting point VPEs.
- **Determine Angle optimizing utilization, using specified increment:** specifies the part rotations aPriori considers in order to optimize nesting. aPriori considers non-negative, whole number multiples of this value that are less than 360 degrees. With a value smaller than the default, costing will be slower, but utilization might increase.
- **Specify Angle [0 = lengthWise, 90 = widthWise]:** specifies the part angle within the part strip.

Pierce Before or After Forms

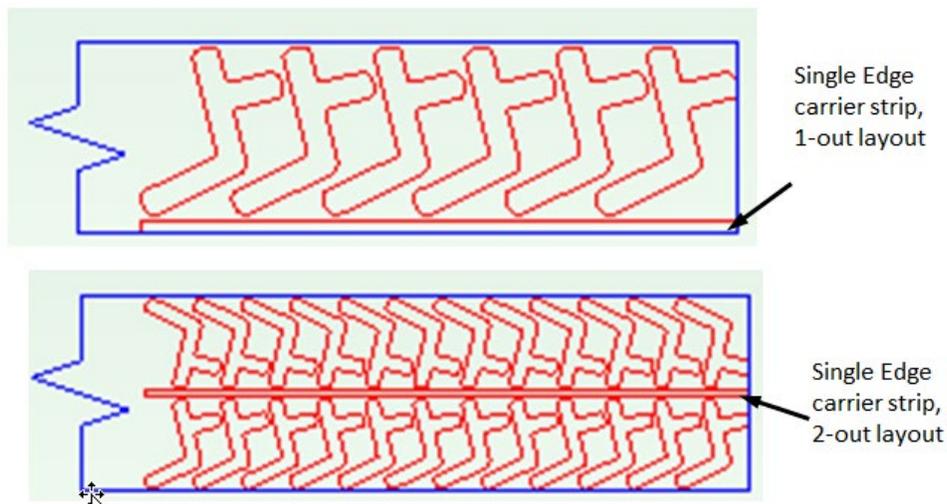
In aPriori starting point VPEs, piercing operations precede forming operations, by default. VPE administrators can customize the default with the cost model variable **holesAfterFormsProgDie**. You can override the default on a per-part basis with this setup option. Select one of the following:

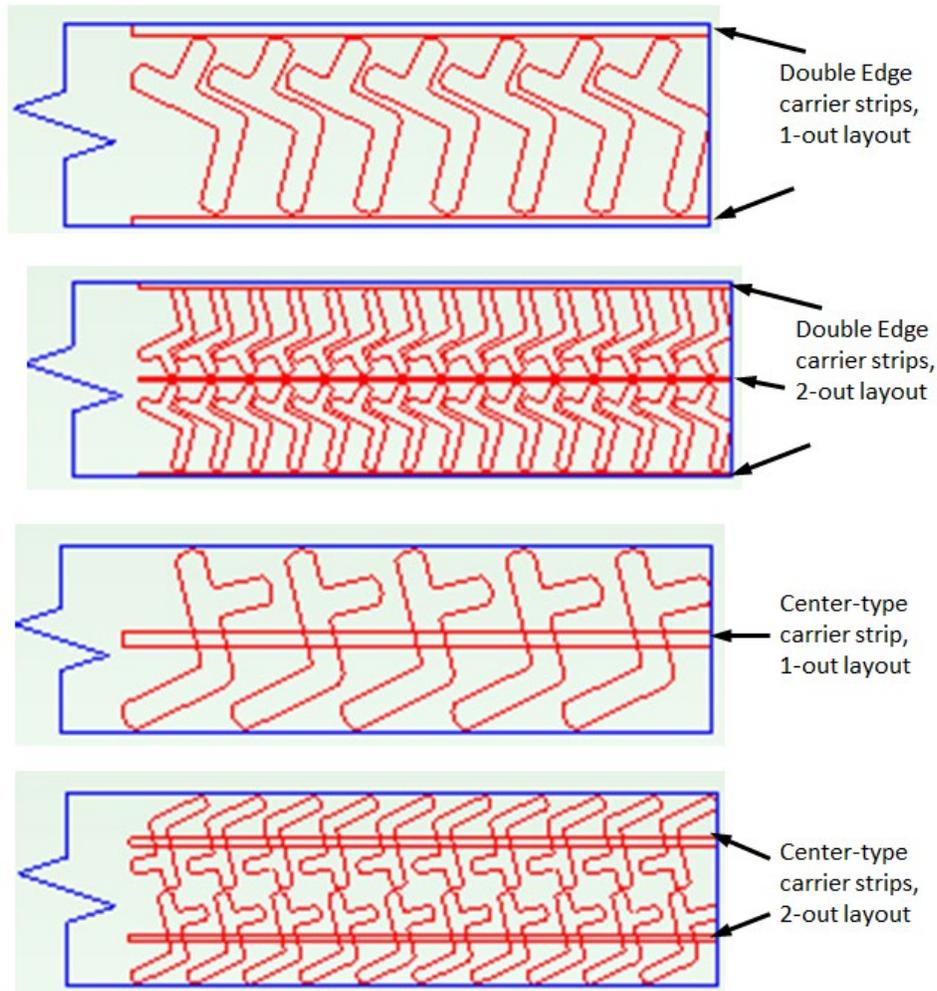
- Default
- User Override: select one of the following:
 - holesBeforeForms
 - holesAfterForms

Press Carrier Strip Type

Number and position of the carrier strips that are used to convey the stamped blanks from die station to die station. Select one of the following options:

- Default: aPriori chooses a default carrier strip type based on the blank's geometry and orientation on the coil. A single edge strip is used unless both the following hold, in which case a center carrier strip is used:
 - The blank is oriented length-wise or width-wise (the blank's SER width or length is parallel to the coil's length—a rotation of 0, 90, 180, or 270 degrees).
 - There is sufficient room on both the leading and trailing sides of the blank (left and right sides of the blank, if the coil flow is left-to-right). The site variable **minCarrierStripTabWidth** specifies the minimum required amount of room.
- User Override:
 - singleEdge: Only one carrier strip is used, located on one side of the row of blanks. For a 2-out layout, the strip is between the rows.
 - doubleEdge: Two carrier strips are used, one on each side of a row of blanks. For a 2-out layout, a total of three strips are used.
 - center: Only one carrier strip is used, located in the middle of each row of blanks.





Single Edge Carrier Strip Width

Width to be added to the coil to accommodate a single edge carrier strip.

In starting point VPEs, The default carrier strip has enough width to accommodate the pilot hole flanked by margins that are 1.5 times material thickness. VPE Administrators can customize the thickness multiplier with the cost model variable **defaultEdgeMarginMultiplier**.

Default Carrier Strip Width =

$$2 * (\text{defaultEdgeMarginMultiplier} * \text{Material Thickness}) + \text{Pilot Hole Diameter}$$

In aPiori starting point VPEs, the pilot hole diameter is 6.35mm for material whose thickness is less than 4mm, and 8mm for material whose thickness is greater than or equal to 4mm.

In general, the diameter is looked up in the global lookup table **toolingComponentAttributes**. The diameter is specified by the table entry **pilotPinStandardDiameterSmall** for material whose thickness is less than the cost model variable **pilotPinSizingThreshold**, and it is specified by the table entry **pilotPinStandardDiameterLarge** for material whose thickness is greater than or equal to **pilotPinSizingThreshold**.

Select one of the following options:

- Default: calculated by aPiori (as described above).

- User Override: enter a value greater than or equal to 0.

(Note that no additional width is required for center-type carrier strips, since they are located in the middle of the row of nested blanks and are assumed never to extend beyond the blank edges.)

Double Edge Carrier Strip Width

Width to be added to the coil to accommodate one edge of a double edge carrier strip.

In starting point VPEs, The default carrier strip has enough width to accommodate the pilot hole flanked by margins that are 1.5 times material thickness. VPE Administrators can customize the thickness multiplier with the cost model variable **defaultEdgeMarginMultiplier**.

Default Carrier Strip Width =

$$2 * (\text{defaultEdgeMarginMultiplier} * \text{Material Thickness}) + \text{Pilot Hole Diameter}$$

In aPiori starting point VPEs, the pilot hole diameter is 6.35mm for material whose thickness is less than 4mm, and 8mm for material whose thickness is greater than or equal to 4mm.

In general, the diameter is looked up in the global lookup table **toolingComponentAttributes**. The diameter is specified by the table entry **pilotPinStandardDiameterSmall** for material whose thickness is less than the cost model variable **pilotPinSizingThreshold**, and it is specified by the table entry **pilotPinStandardDiameterLarge** for material whose thickness is greater than or equal to **pilotPinSizingThreshold**.

Select one of the following options:

- Default: calculated by aPiori (as described above).
- User Override: enter a value greater than or equal to 0.

When you use double-edge type carrier strips with double-row nesting layouts, there are actually 3 strips: one at the top edge of the coil, one at the bottom edge of the coil, and one between the two rows of parts.

See also [Coil Width](#) for more information on how strip width contributes to coil width.

(Note that no additional width is required for center-type carrier strips, since they are located in the middle of the row of nested blanks and are assumed never to extend beyond the blank edges.)

Press French Stop

Specifies whether to use a French stop (a notch on the edge of the coil) in order to keep the coil appropriately aligned with the die stations (the notch acts as a positive stop as the coil advances). If used, extra width must be added to the coil width to provide sufficient space for the notch. Select one of the following options:

- Standard French Stop: add the default extra width for a French stop, the value of the cost model variable **defaultFrenchStopSize** (3.0 mm in aPiori starting point VPEs).
- No French Stop: no extra width is added. This is the default.
- User Override: enter a value greater than or equal to 0, the width to be added.

Blank Pitch

Blank pitch is the extent of the flat pattern (with addendum, if any) along the direction of coil flow, supplemented by addendum widths and center trim strip length or part spacing width. By default, this is calculated using aPriori's strip nesting algorithm. The default value is the sum of the following:

- Extent of the flat pattern in the direction of coil flow, when best nested (as determined by the aPriori strip nesting algorithm)
- Trim Strip Length for Center Carrier Strip, if specified and larger than Part Spacing Width; Part Spacing Width, otherwise

See also the illustrations in [Coil Width](#).

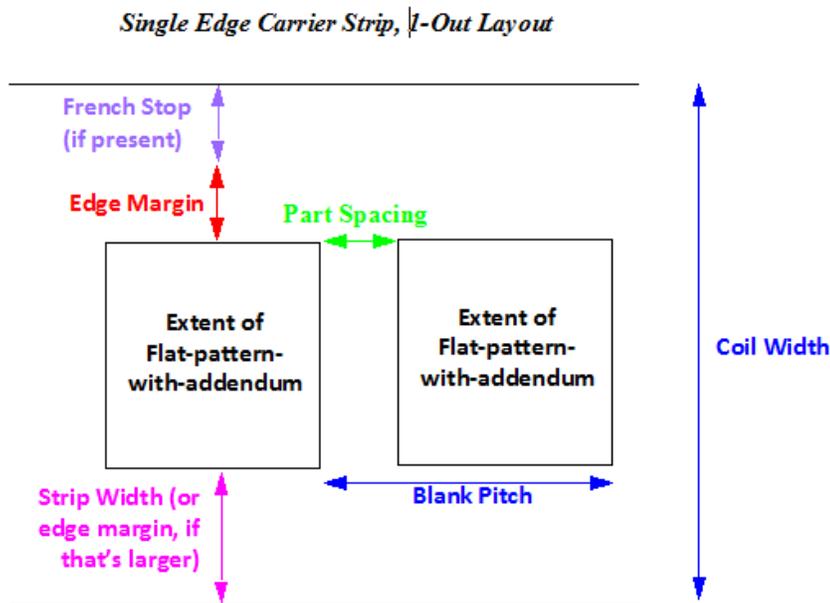
You can override the default with this option, which affects both material utilization and tooling sizes and costs. It is your responsibility to ensure that the overrides have legal results, for example, that the resulting blanks do not overlap.

Select one of the following:

- Default: calculated by aPriori (as described above)
- User Override: enter a value in millimeters or inches that is greater than or equal to 1.0 mm.

Coil Width

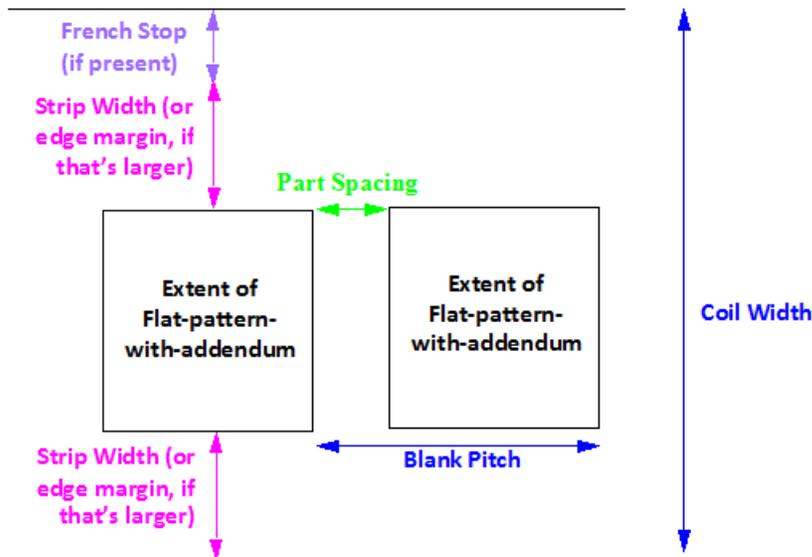
Coil width is the extent of the flat pattern (with addendum, if any) in the direction perpendicular to the coil flow, supplemented by trim strip and French-stop widths. By default, this is calculated using aPriori's strip nesting algorithm.



For a 1-out layout with a single-edge carrier strip, the default value is the sum of the following:

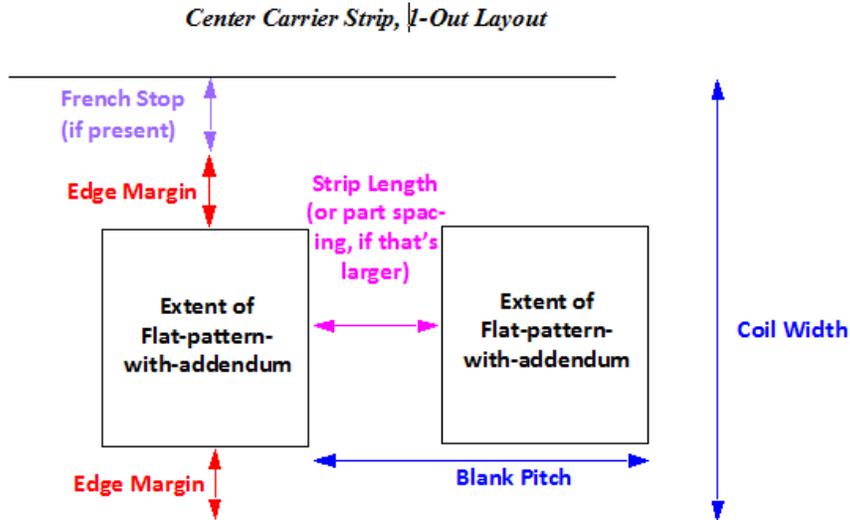
- Extent of the flat pattern (with addendum, if any) in the direction perpendicular to the coil flow, when best nested (as determined by the aPriori strip nesting algorithm)
- Edge Margin Width
- Carrier Strip Width (or Edge Margin Width, whichever is larger)
- Press French Stop width (if present)

Double Edge Carrier Strip, 1-Out Layout



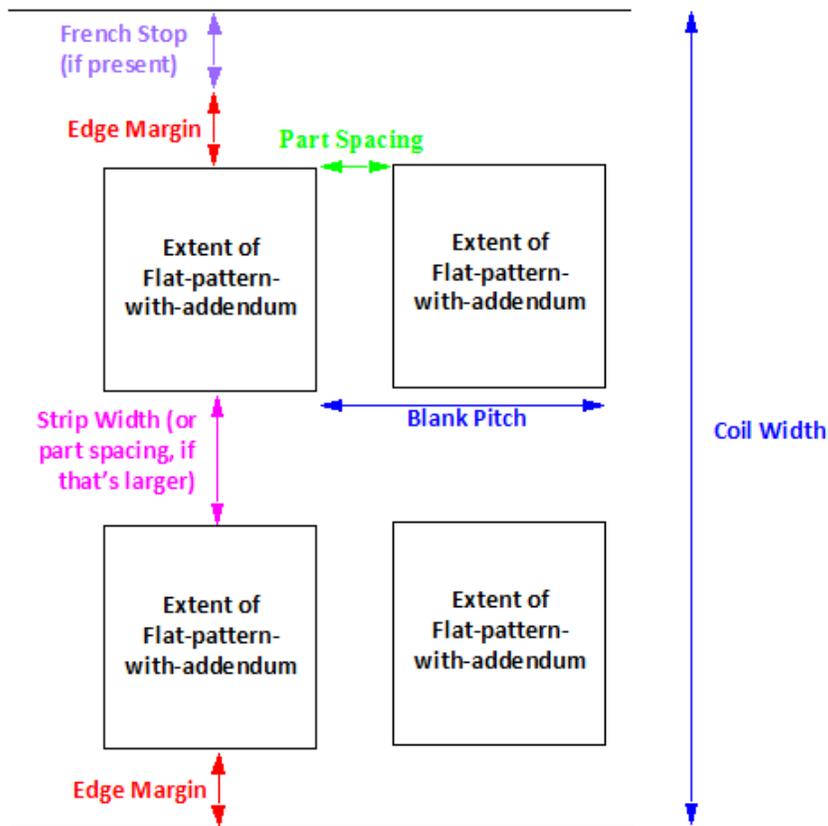
For a 1-out layout with a double-edge carrier strip, the default value is the sum of the following:

- Extent of the flat pattern (with addendum, if any) in the direction perpendicular to the coil flow, when best nested (as determined by the aPriori strip nesting algorithm)
- 2 * Carrier Strip Width (or 2* Edge Margin Width, whichever is larger)
- Press French Stop width (if present)



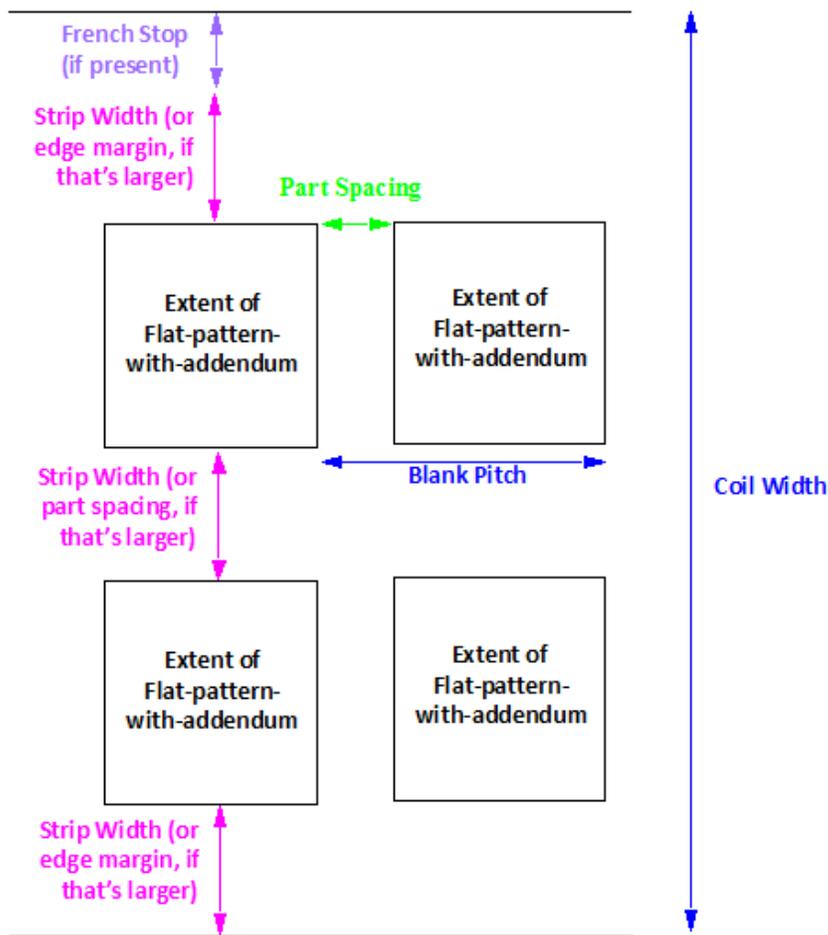
For a 1-out layout with a center carrier strip, the default value is the sum of the following:

- Extent of the flat pattern (with addendum, if any) in the direction perpendicular to the coil flow, when best nested (as determined by the aPriori strip nesting algorithm)
- 2 * Edge Margin Width
- Press French Stop width (if present)

Single Edge Carrier Strip, 2-Out Layout

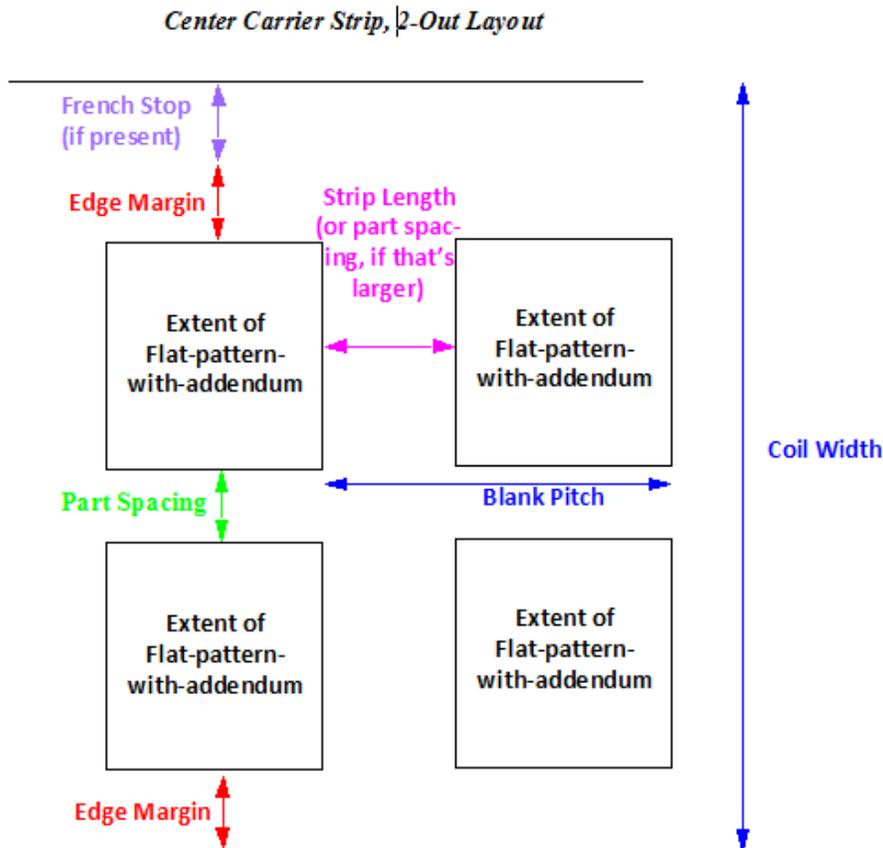
For a 2-out layout with a single-edge carrier strip, the default value is the sum of the following:

- 2 * extent of the flat pattern (with addendum, if any) in the direction perpendicular to the coil flow, when best nested (as determined by the aPriori strip nesting algorithm)
- 2 * Edge Margin Width
- Carrier Strip Width (or Part Spacing Width, whichever is larger)
- Press French Stop width (if present)

Double Edge Carrier Strip, 2-Out Layout

For a 2-out layout with a double-edge carrier strip, the default value is the sum of the following:

- 2 * extent of the flat pattern (with addendum, if any) in the direction perpendicular to the coil flow, when best nested (as determined by the aPriori strip nesting algorithm)
- 2 * Carrier Strip Width (or 2* Edge Margin Width, whichever is larger)
- Carrier Strip Width (or Part Spacing Width, whichever is larger)
- Press French Stop width (if present)



For a 2-out layout with a center carrier strip, the default value is the sum of the following:

- 2 * extent of the flat pattern (with addendum, if any) in the direction perpendicular to the coil flow, when best nested (as determined by the aPriori strip nesting algorithm)
- 2 * Edge Margin Width
- Part Spacing Width
- Press French Stop width (if present)

Note that center-type carrier strips add to coil pitch, but don't add to width.

You can override the default with this option, which affects material utilization, as well as tooling sizes and costs. Note that coil width is constrained by the setup option [Minimum Strip Width](#).

Select one of the following:

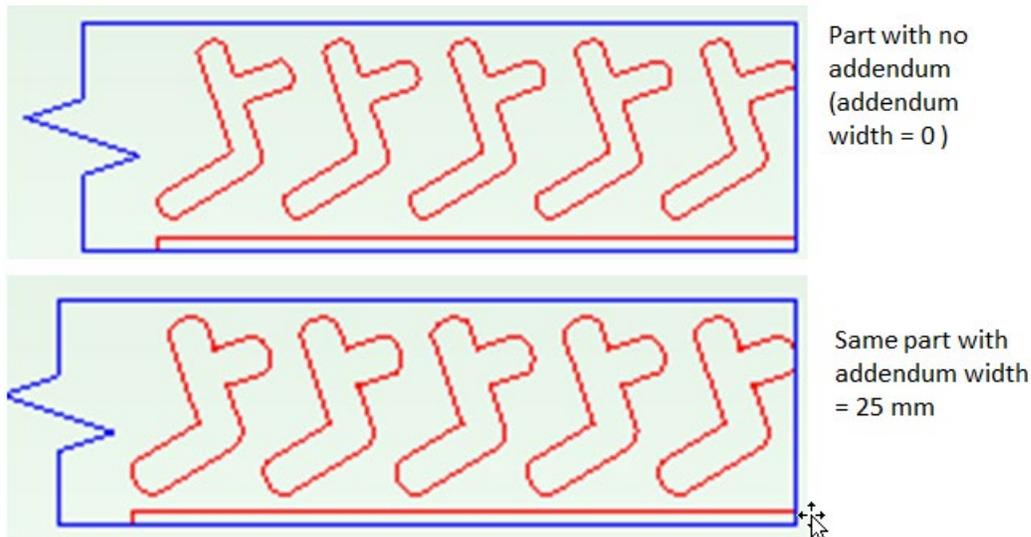
- Default: calculated by aPriori (as described above)
- User Override: enter a value greater than or equal to 0.

Width of Addendum Added to Blank Size [per side]

An offset to be added all around the perimeter of the flattened part. You can enter a non-zero value in order to do one of the following:

- Add additional material for the purpose of holding the blank during the stamping process, which is subsequently trimmed away.

- Compensate for cases in which aPiori underestimates flattened blank size, for example, for highly deformed parts.



Select one of the following options:

- No Addendum: this is the default.
- Computed Based on Form Depth: derived from the lookup table **blankAddendumWidth**.
- User Override: enter a value greater than or equal to 0.

Trim Strip Length for Center Carrier Strip Type

Only used with center-type carrier strips. The carrier strip length for a center carrier strip extends the horizontal spacing between adjacent blanks, in order to provide adequate space for pilot holes located in the carrier strip.

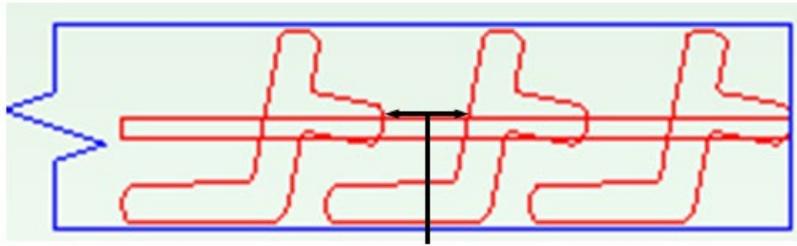
In starting point VPEs, The default carrier strip has enough length to accommodate the pilot hole flanked by margins that are 1.5 times material thickness. VPE Administrators can customize the thickness multiplier with the cost model variable **defaultEdgeMarginMultiplier**.

Default Center Carrier Strip Length =
 $2 * (\text{defaultEdgeMarginMultiplier} * \text{Material Thickness}) + \text{Pilot Hole Diameter}$

In aPiori starting point VPEs, the pilot hole diameter is 6.35mm for material whose thickness is less than 4mm, and 8mm for material whose thickness is greater than or equal to 4mm.

In general, the diameter is looked up in the global lookup table **toolingComponentAttributes**. The diameter is specified by the table entry **pilotPinStandardDiameterSmall** for material whose thickness is less than the cost model variable **pilotPinSizingThreshold**, and it is specified by the table entry **pilotPinStandardDiameterLarge** for material whose thickness is greater than or equal to **pilotPinSizingThreshold**.

The carrier strip length affects the pitch computation only when center carrier strips are in use; it is not applied for single-edge or double-edge carrier strips.



Select one of the following options:

- Default: calculated by aPriori (as described above).
- User Override: enter a value greater than or equal to 0.

See also [Blank Pitch](#).

Edge Margin Width

For a coil edge with no carrier strip, this option specifies the width of the extra space between the flat pattern and the edge (or French Stop if present). For an edge with a carrier strip, this extra space between is specified by the carrier strip width (see [Single Edge Carrier Strip Width](#) and [Double Edge Carrier Strip Width](#)) or the Edge Margin Width, whichever is greater. See also [Coil Width](#).

In aPriori starting point VPEs, the default value is 1.5 times the material thickness. VPE administrators can customize the thickness multiplier with the cost model variable **defaultEdgeMarginWidthMultiplier**.

Select one of the following options:

- Default: in aPriori starting point VPEs, the default value is 1.5 times the material thickness. VPE administrators can customize the thickness multiplier with the cost model variable **defaultEdgeMarginMultiplier**.
- User Override: enter a value greater than or equal to 0.

Part Spacing Width

Width of extra space between adjacent blanks. This value specifies both the distance between blanks in the coil pitch direction (in the absence of a center carrier strip), as well as the distance in the coil width direction between rows of a 2-out layout (if a center carrier strip is used). See also [Coil Width](#) and [Blank Pitch](#).

In aPriori starting point VPEs, the default value is 1.5 times the material thickness. VPE administrators can customize the thickness multiplier with the cost model variable **defaultPartSpacingMultiplier**.

Select one of the following options:

- Default: in aPriori starting point VPEs, the default value is 1.5 times the material thickness. VPE administrators can customize the thickness multiplier with the cost model variable **defaultPartSpacingMultiplier**.
- User Override: enter a value greater than or equal to 0.

Heat Treat of Die Components

Die components are heat treated by default. This option provides a dropdown list with the following items:

- Yes: perform heat treatment.

- No: do not perform heat treatment.

To override heat treatment, select **No** from the dropdown list.

Plating of Die Components

By default, the material used for die plating depends on the base tool material (see **Base Tool Material**). High-strength materials use the plating specified by the cost model variable **highStrengthMatlToolingCoatingType** (DuplexVariantic in starting point VPEs). Base material S7 uses Nitride plating. Base material D2 uses CVD plating. Any other base material uses the plating specified by the cost model variable **defaultToolingCoatingType** (Nitride in starting point VPEs).

High-strength material is defined as material with a tensile yield strength of 344.74 Mpa in starting point VPEs. VPE administrators can customize this threshold with the cost model variable **highStrengthMatlThreshold**.

To specify plating material explicitly, select one of the following options:

- None
- Nickel
- Chrome
- Nitride
- Teflon
- Tribo-Coating
- DuplexVariantic
- CVD

Base Tool Material

This is used to determine tool plating costs. By default, base tool material is S7. To specify base tool material explicitly, select one of the following options:

- D2
- A2
- S7

Stamp Assembly Qty

Select one of the following options:

- Default: specified by the cost model variable **defaultStampAssemblyQty**.
- User Override: enter a value greater than or equal to 0.

Number of 150, 300, 600, 800, 1000, 1200 Series Cam Units

Select one of the following options:

- Default
- User Override: enter a value greater than or equal to 0.

Freight Cost

Freight cost applied to tooling defaults to 0. To explicitly specify a tooling freight charge, enter a value greater than or equal to 0.

Total Carrying Cost

This is the cost for holding the completed tool in inventory prior to shipping. Total carrying cost applied to tooling defaults to 0. To explicitly specify a tooling carrying cost, enter a value greater than or equal to 0.

Total Gage Cost

Total gage cost applied to tooling defaults to 0. To explicitly specify a tooling gage cost, enter a value greater than or equal to 0.

Total Welding Cost

Total welding cost applied to tooling defaults to 0. To explicitly specify a tooling welding cost, enter a value greater than or equal to 0.

Add IDLE Station Before CUTOFF Station

In starting point VPEs, aPriori adds an idle station before the cutoff station, by default. VPE administrators can customize the default with the cost model variable **addIdleBeforeCutoffEnabled**. With this PSO, you can override the default on a per part basis. To explicitly specify whether to add an idle station, select one of the following options:

- Default: value of cost model variable **addIdleBeforeCutoffEnabled**, which is set to **Yes** in aPriori starting point VPEs.
- User Override: select **Yes** or **No**.

Add IDLE Station Following TRIMMING Station if Blank Pitch is Less Than This

In starting point VPEs, aPriori adds an idle station after a trimming station if the blank pitch is less than 80mm, by default. VPE administrators can customize this threshold with the cost model variable **defaultBlankPitchThreshold**. With this PSO, you can override the default threshold on per part basis. To explicitly specify a blank pitch threshold, select one of the following options:

- Default
- User Override: enter a value greater than or equal to 0.

Maximum Strip Width

If aPriori calculates a required width (see [Coil Width](#)) that is greater than this value, the part fails to cost. In aPriori starting point VPEs, the maximum allowable strip width is 1828.8mm, by default. VPE administrators can customize the default with the cost model variable **maximumStripWidth**. You can override the default for the current part with this setup option. Select one of the following:

- Default
- User Override

Minimum Strip Width

This value constrains the choice of material stock. If aPriori calculates a required width (see [Coil Width](#)) that is less than this value, this value is used instead of the calculated value in order to determine material and tooling costs.

By default, the minimum allowable strip width is the calculated required strip width. You can override the default for the current part with this setup option. Select one of the following:

- Default
- User Override

Enable SCORING Operations for Bends

In aPriori starting point VPEs, bends are not scored by default. VPE administrators can customize the default with the cost model variable **scoreBendsProgDie**. You can override the default with this PSO. Select one of the following options:

- Default: specified by the cost model variable **scoreBendsProgDie** (**No** in aPriori starting point VPEs).
- User Override: select **Yes** or **No**.

Enable COINING Operations for SimpleHoles

In aPriori starting point VPEs, flanged, tapped holes are coined, by default. VPE administrators can customize the default with the cost model variable **enableCoiningFlangedHoles**. You can override the default with this PSO. Select one of the following options:

- Default: specified by the cost model variable **enableCoiningFlangedHoles** (**Yes** in aPriori starting point VPEs).
- User Override: select **Yes** or **No**.

Enable SHAVING Operatoins for SimpleHoles

In aPriori starting point VPEs, flanged, tapped holes are shaved, by default. VPE administrators can customize the default with the cost model variable **enableShavingFlangedHoles**. You can override the default with this PSO. Select one of the following options:

- Default: specified by the cost model variable **enableShavingFlangedHoles** (**Yes** in aPriori starting point VPEs).
- User Override: select **Yes** or **No**.

Enable Restriking Operation for Straight and Curved Bends

In aPriori starting point VPEs, restriking is *not* performed on bends, by default. VPE administrators can customize the default with the cost model variable **enableRetrikingStraightCurvedBends**. You can override the default with this PSO. Select one of the following options:

- Default: specified by the cost model variable **enableRetrikingStraightCurvedBends** (**No** in aPriori starting point VPEs).
- User Override: select **Yes** or **No**.

Enable Standalone Piloting Operation

In starting point VPEs, piloting is combined with edge trimming on the first die station, by default. VPE administrators can customize the default with the cost model variable **enableStandalonePiloting**. You can override the default on a per-part basis with this PSO.

Note that this typically increases the total number of die stations. Select one of the following options:

- Default: specified by the cost model variable **enableStandalonePiloting** (**No** in starting point VPEs).
- User Override: select **Yes** or **No**.

Set Number of Trimming Operations

By default, aPriori calculates the number of trimming stations. You can override the default with this PSO. Select one of the following options:

- Default: calculated by aPriori.
- User Override: enter a value between 0 and the cost model variable **maxTrimStagesProgDie** (4 in aPriori starting point VPEs).

Enable In Die TAPPING operations

In aPriori starting point VPEs, in-die tapping is disabled by default. VPE administrators can customize the default with the cost model variables **defaultEnableInDieTapping**. You can override the default with this PSO. Select one of the following options:

- Default: specified by the cost model variables **defaultEnableInDieTapping** (**No** in aPriori starting point VPEs).
- User Override: select either **Yes** or **No**.

Add Idle Station Before After Tapping

In aPriori starting point VPEs, an Idle station is added before and after a Trimming station, by default. VPE administrators can customize the default with the cost model variable **addIdleBeforeAfterTappingEnabled**. You can override the default with this PSO. Select one of the following options:

- Default: specified by the cost model variable **addIdleBeforeAfterTappingEnabled** (**Before and After** in aPriori starting point VPEs).
- User Override: select one of the following:
 - **Before**
 - **After**
 - **Before and After**
 - **None**

Add Idle Station After Trimming

In aPriori starting point VPEs, an Idle station is added after a Trimming station, by default. VPE administrators can customize the default with the cost model variable **addIdleAfterTrimming**. You can override the default with this PSO. Select one of the following options:

- Default: specified by the cost model variable **addIdleAfterTrimming** (**Yes** in aPriori starting point VPEs).
- User Override: select **Yes** or **No**.

Add Idle Station After Cam Forming

In aPriori starting point VPEs, an Idle station is added after a Cam Forming station, by default. VPE administrators can customize the default with the cost model variable **addIdleAfterCamForming**. You can override the default with this PSO. Select one of the following options:

- Default: specified by the cost model variable **addIdleAfterCamForming** (Yes in aPriori starting point VPEs).
- User Override: select **Yes** or **No**.

Add Idle Station After Cam Trimming

In aPriori starting point VPEs, an Idle station is added after a Cam Trimming station, by default. VPE administrators can customize the default with the cost model variable **addIdleAfterCamTrimming**. You can override the default with this PSO. Select one of the following options:

- Default: specified by the cost model variable **addIdleAfterCamTrimming** (Yes in aPriori starting point VPEs).
- User Override: select **Yes** or **No**.

Add Idle Station After Cam Bending

In aPriori starting point VPEs, an Idle station is added after a Cam Bending station, by default. VPE administrators can customize the default with the cost model variable **addIdleAfterCamBending**. You can override the default with this PSO. Select one of the following options:

- Default: specified by the cost model variable **addIdleAfterCamBending** (Yes in aPriori starting point VPEs).
- User Override: select **Yes** or **No**.

Add Idle Station After Cam Piercing

In aPriori starting point VPEs, an Idle station is added after a Cam Piercing station, by default. VPE administrators can customize the default with the cost model variable **addIdleAfterCamPiercing**. You can override the default with this PSO. Select one of the following options:

- Default: specified by the cost model variable **addIdleAfterCamPiercing** (Yes in aPriori starting point VPEs).
- User Override: select **Yes** or **No**.

Number of Shear Planes

By default in starting point VPEs, shear force is calculated on the assumption that cluster punching is *not* used (that is, on the assumption of a single shear plane, with all GCDs pressed at the same time). VPE administrators can customize the default number of shear planes with the cost model variable **numShearPlanes**. In addition, users can override the default on a per-part basis with this setup option.

Multiple shear planes indicate the use of cluster punching, with different groups of GCDs pressed in a staggered fashion, rather than simultaneously. Required press force

decreases as the number of shear planes increases. A decrease in required press force can sometimes lower costs due to selection of a lower-overhead machine.

Tandem Die Process Setup

Process setup options may be accessed from the Manufacturing Process panel by highlighting the Tandem Die process and selecting **Edit > Process Setup Options**.

For Tandem Die parts, aPiori allows you to define values and options for the following cost drivers:

- Transfer method – robotic or manual
- Trim strip applied to material width (per side)
- Trim strip applied to material length (per side)
- Number of parts stamped concurrently
- Number of parts stamped concurrently - lengthwise
- Number of parts stamped concurrently - widthwise
- Pierce holes before or after forms

Transfer method – robotic or manual

Transfer Method may be specified as Robotic or Manual for the Tandem Die Process. Tandem Die with Manual transfer selected is modeled is approximately equivalent to the Stage Tooling Process.

Trim strip applied to material width (per side)

Trim strip applied to material width (per side or center) may be specified in the following ways:

- Default value
- Override value

Trim strip applied to material length (per side)

Trim strip applied to material length may be specified in the following ways:

- Default value
- Override value

Number of parts stamped concurrently

Number of Parts Stamped Concurrently at each press station may be specified in the following ways:

- Number of Concurrent Parts = Lengthwise x Widthwise
- Mirrored Part (2)

Number of parts stamped concurrently - lengthwise

Number of Parts Stamped Concurrently may be specified in the following ways:

- Default value (1)

- Override value – you specify number

Number of parts stamped concurrently - widthwise

Number of Parts Stamped Concurrently may be specified in the following ways:

- Default value (1)
- Override value – you specify number

Pierce holes before or after forms

You may specify that holes are to be pierced after forming by checking this option. Default is to pierce prior to forming.

Design-to-cost Configuration for Sheet Metal

See [Design-to-cost Configuration for Sheet Metal](#).

13 Sheet Metal-- Hydroforming

The Sheet Metal—Hydroforming process group lets you estimate manufacturing times and costs for sheet hydroforming fabrication processes and subsequent machining operations. The cost model includes estimates of hard tooling costs. This chapter describes the costing details and inputs that are available for the Sheet Metal—Hydroforming process group. For detailed information on other sheet metal processes, see the chapters [Sheet Metal—Hard Tooled](#) and [Sheet Metal—Soft Tooled](#), [Sheet Metal—Transfer Die](#), and [Sheet Metal—Stretch Forming](#).

This chapter has the following sections:

- [Cost Model Overview for Hydroforming](#)
 - [GCD Extraction for Hydroforming](#)
 - [Routing and Feasibility for Hydroforming](#)
 - [Material Stock Selection for Hydroforming](#)
 - [Machine Selection for Hydroforming](#)
 - [Formulas for Hydroforming](#)
 - [User Inputs for Hydroforming](#)
-

Cost Model Overview for Hydroforming

Hydroforming is a die-based forming process that uses high-pressure hydraulic fluid to press room-temperature material blanks into various shapes. The blank and the hydraulic fluid are usually separated by a rubber bladder. The cost model supports two types of sheet hydroforming: Deep Draw and Fluid Cell. With a Deep Draw machine, the tool rests on a lower tray that can be displaced to create form depth. With a Fluid Cell machine, the tool rests on a stationary lower tray. Fluid Cell machines can be used to create bends, relatively shallow and simple forms, and some undercuts.

This overview has the following sections:

- [General Process for Hydroforming](#)

- GCDs for Hydroforming
- Material and Stock Forms for Hydroforming
- Material Utilization and Part Nesting for Hydroforming
- Machines for Hydroforming
- Tooling for Hydroforming

General Process for Hydroforming

The Hydroforming process group provides the following main processes:

- Blanking process: blanking is performed by one of the following soft-tooled processes (which are in the Sheet Metal process group):
 - 2 Axis Router
 - Laser Cut

The blanking process creates the blank that will be formed by the Hydroforming process, and also creates the part's holes, if none have high tolerance or would be distorted by subsequent forming.

The cost model also supports routings that perform blanking (and feasible hole making) with an alternative, shear-based process, Offline Blanking. This hard-tooled process uses coil stock fed into a blanking press.

- Hydroform: this process includes operations for cleaning the tool, loading the blank onto the hydroform machine, forming the blank, unloading the formed part from the machine, and inspecting the part. It also can include an operation for hand adjustment of forms.

There are two types of hydroforming routings: fluid cell routings and deep draw routings. Both types of routings use the Hydroform process, but they use different types of Hydroform machines (see [Cost Model Overview for Hydroforming](#)), and different component-level operations, Hydroform Fluid Cell and Hydroform Deep Draw. The cost model evaluates the feasibility of using each type of routing, in part, by considering various depth-to-width ratios associated with the part's forms.

For some parts, multiple fluid cell or deep draw cycles are required. Parts are annealed between cycles (using the Standard Anneal process in the Heat Treatment process group).

There are also two utilization processes (which are responsible for stock selection and material utilization calculations):

- Coil Material Stock: included in routings that use Offline Blanking.
- Sheet Material Stock: included in routings that use 2 Axis Router or Laser Cut for blanking.

Routings also include the Bench Operation process from the Sheet Metal—Stretch Forming process group. This process includes operations for final cleaning and inspection of the formed part.

Secondary machining (the Trim Drill sequence on the 5-Axis Mill) is included for parts whose blanks include addendum (to accommodate deep forms or high-tolerance edges),

and for parts with holes that have high tolerance or would be distorted by subsequent forming.

Note that, even though blanking is actually performed before forming, Laser Cut or 2 Axis Router always appear in the Manufacturing Process pane *after* the processes in the Hydroform process group. Similarly, even though annealing is actually performed between forming draws, Standard Annealing always appears in the Manufacturing Process pane *after* the processes in the Hydroform process group.

See [Routing and Feasibility for Hydroforming](#) for more information.

GCDs for Hydroforming

Following are some of the important GCDs used by the Hydroforming process group:

- **Blank GCD:** this GCD represents the flattened part. aPriori calculates the blank's outline (including any addendum deemed necessary by the cost model), and determines an efficient nesting of the blank on sheet or coil stock. Blanks are created by Router Cut, Laser Cut, or Offline Blanking, and then loaded onto the Hydroforming machine.
- **Xsection GCD:** these GCDs represent part cross-sections in planes orthogonal to the ram direction. The cost model examines their arrangement and widths in order to evaluate process feasibility and determine the number of draws required for the part.
- **Ram Direction GCD:** this GCD represents the direction (relative to the part) from which the bladder approaches the blank. aPriori's choice of ram direction reflects how the part is assumed to be oriented in the hydroforming press. The Ram Direction points up, from the lower tray or punch of the machine toward the bladder. You can use the Ram Direction tool to override aPriori's choice of ram direction (for example, in order to ensure that the blank can lie flat on a large area of the tool before forming).
- **Main Surface GCD:** this GCD consist of a group of associated surfaces, and represents a portion of the part that retains a relatively stable orientation relative to the hydroforming press table throughout the forming process. Relations involving the MainSurface help the cost model to identify the part's primary forms, and to determine which of the part's holes can be created prior to forming.
- **Form GCD:** each of these GCDs is collection of surfaces that represents a feature that is created by forming, and is classified as either a curved bend or emboss. By using the Form Definition dialog, you can change a form's classification or override the extracted surface groupings.
- **StraightBend GCD:** these GCDs are among the features that can be created by the forming tool in hydroforming. Properties that play an important role in the hydroforming cost model include Bend Direction and Bend Flap Size.

See [GCD Extraction for Hydroforming](#) for more information.

Material and Stock Forms for Hydroforming

Hydroforming parts are made from either sheet stock or coil stock, depending on the blanking process used (see [General Process for Hydroforming](#)).

For Router Cut and Laser Cut, standard sheet stock dimensions (specified by cost model variables) are used, provided such stock is big enough for the blank, taking into account trim strips and any blank addendum. See [Material Stock Selection for Laser Cut and Router Cut Routings](#).

For Offline Blanking (shear-press based blanking), coil stock width is based on the extent of the strip-nested flat pattern (with addendum, if any) in the direction perpendicular to the coil flow, supplemented by edge margins, as well as (for 2-out parts) part spacing width. See [Coil Width](#) for more information.

Note to VPE Administrators: Actual coil stocks are *not* supported. Do not add actual stock to a Sheet Metal--Hydroforming VPE.

Materials include the following types:

- Aluminum
- Copper
- Galvanized Steel
- Stainless Steel
- Steel
- Titanium

Material composition details include the following:

- Unit Cost
- Density (kg/m³)
- Tensile Yield Strength (MPa)

Part flattening (to determine blank shape) sometimes takes into account additional material properties, including the following:

- Young's Modulus
- Poisson's Ratio, K (strain-hardening coefficient)
- N (strain-hardening exponent)
- R (Lankford parameter, average)

See [Flattening for Hydroforming](#) for more information.

Material details include equivalent DIN and EN name standards for use with regional VPEs.

Note: If you change the selected material for a part, the part's CAD file must be accessible to aPriori so that it can recalculate the flattened part outline.

See also [Material Utilization and Part Nesting for Hydroforming](#).

Material Utilization and Part Nesting for Hydroforming

The material cost of a sheet metal part is based on the rough mass required to make the part. The utilization is equal to the finish mass of the part divided by the rough mass—rough mass includes any material scrap.

aPriori provides multiple methods for computing sheet metal material utilization. A true-part shape nesting (TPSN) algorithm is used by default for the blanking processes. In order to maximize material utilization and minimize waste, this algorithm finds the

tightest nesting for parts using the blank's actual perimeter. Note that the TPSN algorithm used for coil stock (with Offline Blanking) differs from the TPSN algorithm used for sheet stock (with Laser Cut and Router Cut) in the following respect:

- Coil stock: uses an optimized strip-nesting algorithm in which parts are nested in rows, and all parts in a row have consistent orientations.
- Sheet stock: allows neighboring parts to have different orientations, and doesn't constrain parts to be organized into rows.

The **Material Selection** dialog (in the Manufacturing Process pane) provides you with four options for calculating utilization:

- **Rectangular Nesting:** assumes the part is rectangularly nested on a sheet, with either a lengthwise or widthwise orientation (whichever is more efficient).
- **True-Part Nesting** (strip nesting): uses the component's actual perimeter to determine nesting, and tests various rotations of the component. See also [Blank GCD](#) for more information on transfer die strip nesting.
- **Machine Default:** uses the current machine's associated average material utilization (the machine property **Avg Utilization**); use this to estimate material costs for dynamic nesting.
- **Override:** uses a fixed utilization value entered by user; use this when you know the exact utilization based on a supplier's nesting pattern.

VPE administrators can customize the default utilization method with the cost model variable **defaultUtilizationMethod**. True-part nesting is the out-of-the-box default.

The current nesting pattern for the currently selected stock is viewable in the Viewer using the **Analysis** menu. See [Blank GCD](#).

Setup options are available for controlling aspects of the nesting layout, including trim strips, margins, part spacing, and addenda—see [Sheet Material Stock Options](#) and [Coil Material Stock Options](#).

Machines for Hydroforming

The following tables list important machine property value ranges. Ranges are listed below for those processes in the Hydroforming process group that support a choice of machines:

Offline Blanking

Property	Low End	High End
Press Force (kN)	658.00	10,000.00
Press Table Length (mm)	703.00	5,181.60
Press Table Width (mm)	609.60	2,590.80
Shut Height (mm)	330.00	1,372.00

Hydroform

Property	Low End	High End
Max Pressure (N/mm ²)	68.90	140.00
Lower Punch Force (kN)	3786.33	314,666.67
Forming Area Length (mm)	957.50	3770.00
Forming Area Width (mm)	425.00	1800.00
Forming Area Diameter (mm)	304.80	1066.00
Max Draw Depth (mm)	139.70	400.00

Note that a Hydroform machine with a rectangular tray has a value of 0 for the machine property **Forming Area Dia**. Similarly, a hydroforming machine with a circular tray has a value of 0 for both the machine properties **Forming Area Length** and **Forming Area Width**. You must follow this convention if you add new machines to a Hydroforming VPE.

Note also that the machine property **Lower Punch Force** applies only to deep-draw hydroform machines (see [Machine Feasibility for Hydroform](#)).

See also [Machine Selection for Hydroforming](#).

Tooling for Hydroforming

The processes Hydroform and Offline Blank both require hard tooling. For each, costs for tooling are calculated for the following categories:

- Material
- Design labor
- Machining labor
- Miscellaneous services (such as freight, SG&A, and tuning)
- Tryout cost

The Investment tab provides an itemized estimate of tooling costs:

Validation	Part Summary	Design to Cost	Cost Summary	Part Details	Investment	
Edit ▾						
Name	Tool Name	Type Name	Value	Unit		
Current:						
TOTAL (Hard Tooling)	-	-	23,819.46	USD		
Hydroform Fluid Cell	Blank Holder Tool Cost	Hard Tooling	0.00	USD		
Hydroform Fluid Cell	Blank Holder Tool Labor Cost	Hard Tooling	0.00	USD		
Hydroform Fluid Cell	Blank Holder Tool Material Cost	Hard Tooling	0.00	USD		
Hydroform Cycles	Draw Ring Count	Hard Tooling	0.00			
Hydroform Cycles	Draw Ring Labor Cost (per ring)	Hard Tooling	0.00	USD		
Hydroform Cycles	Draw Ring Material Cost (per ring)	Hard Tooling	0.00	USD		
Hydroform Cycles	Draw Ring Total Cost	Hard Tooling	0.00	USD		
Hydroform Fluid Cell	Forming Tool Cost	Hard Tooling	5,297.02	USD		
Hydroform Fluid Cell	Forming Tool Labor Cost	Hard Tooling	3,100.73	USD		
Hydroform Fluid Cell	Forming Tool Material Cost	Hard Tooling	122.51	USD		
Hydroform Fluid Cell	Forming Tool Misc Services Cost	Hard Tooling	1,038.20	USD		
Hydroform Fluid Cell	Forming Tool Tryout Cost	Hard Tooling	1,035.59	USD		
Hydroform Fluid Cell	Intensifier Tool Cost	Hard Tooling	0.00	USD		
Bench Operation	Manual Form Block	Hard Tooling	0.00	USD		
Offline Blank	Offline Blanking Tool Labor Cost	Hard Tooling	7,727.85	USD		
Offline Blank	Offline Blanking Tool Material Cost	Hard Tooling	3,021.62	USD		
Offline Blank	Offline Blanking Tool Misc Services Cost	Hard Tooling	3,606.79	USD		
Offline Blank	Offline Blanking Tool Tryout Cost	Hard Tooling	4,066.17	USD		
Hydroform Cycles	Total Capping Tool Cost	Hard Tooling	100.00	USD		
Offline Blank	Total Offline Blanking Tool Cost	Hard Tooling	18,422.43	USD		
Hydroform Fluid Cell	Total Tools On Tray	Hard Tooling	1.00			

For Hydroforming, tooling costs increase with the number of required forming cycles, since a different tool is used for each cycle. For deep draw routings, later cycles require taller, more expensive tools.

For fluid cell routings, the cost of an intensifier is included if the part has a bend whose minimum radius is less than or equal to three times the blank thickness.

For Hydroform and Offline Blank, the tooling model estimates the number of parts that can be produced with a given tool before it wears to the point that it needs to be replaced. Based on that estimate, the cost model determines the number of tools required to manufacture the production volume specified in the Production Scenario tab of the Cost Guide, and accounts for that number of tools in total hard tooling cost.

Tool-life estimation is based on part material (see **tblToolLife**), and adjusted for tool material (with a factor specified by the tool shop variable **Tool Life Factor**) and tool coating type (with a factor specified in **tblToolCoating**). For a given costing, either the formula Dependencies or Investment tab displays the number of tools assumed by tooling cost calculations.

For Offline Blank, several setup options affect die height, which is a major driver of tool material cost:

- Post Height Multiplier
- Part Height Allowance
- Minimum Part Height Plus Allowance

For both Hydroform and Offline Blank, VPE administrators can use cost model variables to configure tooling, including in the following areas:

- Number and type of various mold components
- Labor time for various tool-making tasks
- Rate at which various tool-making tasks can be performed

See the **Variables** table for Sheet Metal—Hydroforming, in the VPE Manager.

GCD Extraction for Hydroforming

This section describes some of the important GCDs in the Hydroforming process group:

- Blank GCD
- Xsection GCD
- Ram Direction GCD
- Main Surface GCD
- Form GCD

Blank GCD

The Blank GCD is specific to the Sheet Metal process groups. It represents the flattened part. Its properties (such as **Perimeter**, **Thickness**, **SER Length**, and **SER Width**) are listed in the Geometric Cost Drivers pane, and are all *independent* of the blank's orientation on the stock coil or sheet during offline blanking or laser cutting.

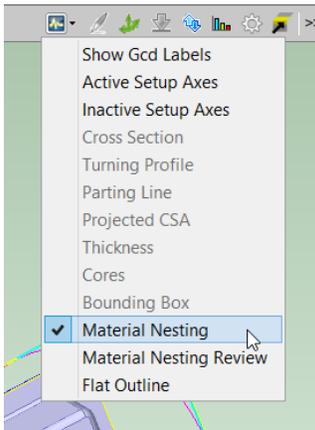
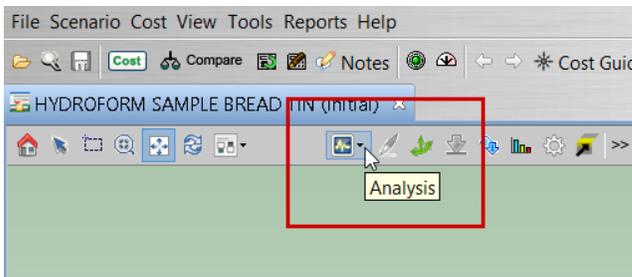
When you select the Blank GCD in the Geometric Cost Drivers pane, the Viewer displays the following:

- Blank outline in pink

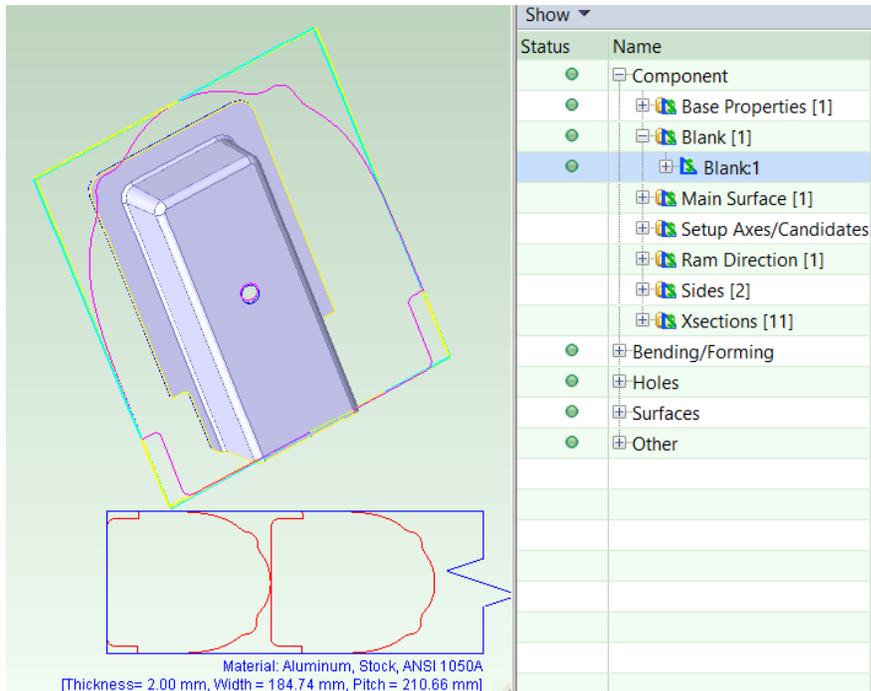
- Blank SER in yellow: this is the smallest-area rectangle that encloses the blank.
- Blank SWER in blue: this is the smallest-width rectangle that encloses the blank (used primarily by the Transfer Die process group).

Geometric Cost Drivers				
Show ▾				
Status	Name	O...	Name	Property Re
●	Component		Name	Blank:1
●	Base Properties [1]		Area (mm^2)	29,413.26
●	Blank [1]		Perimeter - 3D (mm)	595.47
●	Blank:1		Perimeter - 2D (mm)	659.15
	Main Surface [1]		SER Length (mm)	198.66
	Setup Axes/Candidates		SER Width (mm)	172.59
	Ram Direction [1]		Thickness (mm)	2.00
	Sides [2]		SWER Length (mm)	198.99
	Xsections [11]		SWER Width (mm)	172.58
●	Bending/Forming		Chamfer Direction	UNKNOWN
●	Holes		Curved Length (mm)	57.52
●	Surfaces		Is Chamfered	false
●	Other		Max Radius (mm)	84.95
			Min Radius (mm)	2.53
			Number Of Coining	0

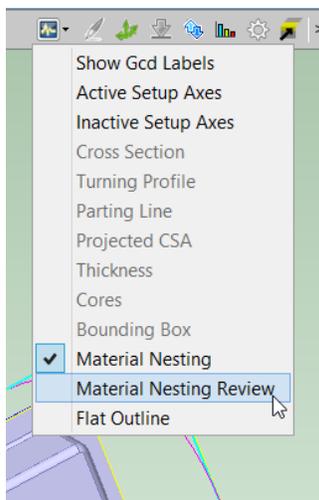
To view the orientation of the blank on the stock, select **Material Nesting** from the Analysis menu in the Viewer toolbar.



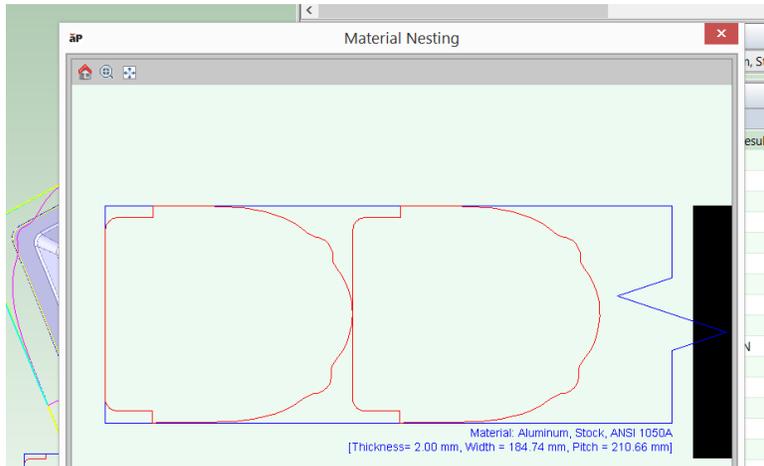
The nesting analysis appears at the bottom of the viewer.



Alternatively, select **Material Nesting Review** from the Analysis menu in the Viewer toolbar.

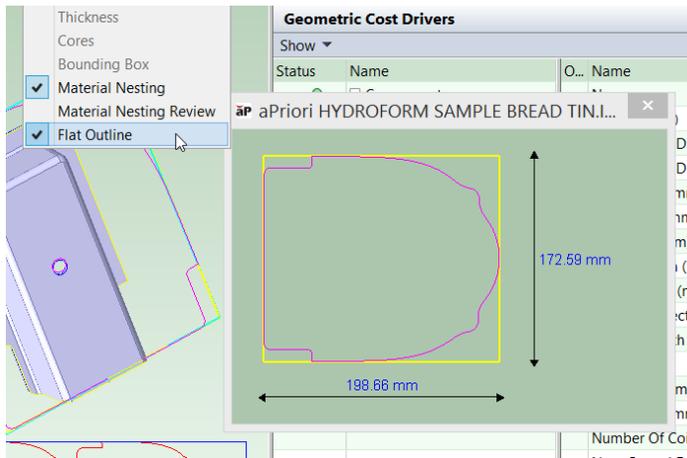


The nesting analysis appears in a new window.



See also [Material Utilization and Part Nesting for Hydroforming](#).

You can display the flat pattern head on, in a separate window, together with its associated SER, by selecting **Flat Outline** from the Analysis menu in the Viewer toolbar.



Blank SER/SWER Length and Width Versus Blank Pitch and Coil Width

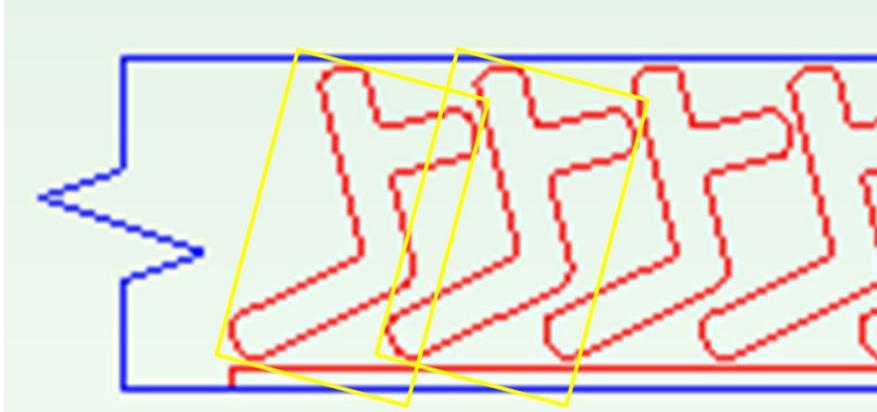
It is very important to distinguish between the following rectangles that enclose the flattened part:

- Blank's SER or SWER: these rectangles' dimensions are independent of the blank's orientation on the stock coil or sheet; that is, **SER Length**, **SER Width**, **SWER Length**, and **SWER Width** do not change if the blank's nesting or orientation change.
- Nested blank's extent rectangle: this is a rectangle that
 - Contains all of the flattened part
 - Has sides that are each either parallel or perpendicular to the sides of the material stock.
 - Encloses extra material around the flattened part for various purposes.

The dimensions, blank pitch and coil width, of this extent rectangle *do* depend on the blank's orientation on the coil; these dimensions can change if the orientation changes. See [Blank Pitch and Coil Width](#).

Some users might be used to using the term “blank” to refer to the extent rectangle described above; but this is *not* what the Blank GCD represents. The Blank GCD represents the flattened part, whose **SER Width** and **SER Length** are independent of nesting and orientation.

The figure below shows nested Blanks oriented on the stock coil. The Blank SERs are shown in yellow.



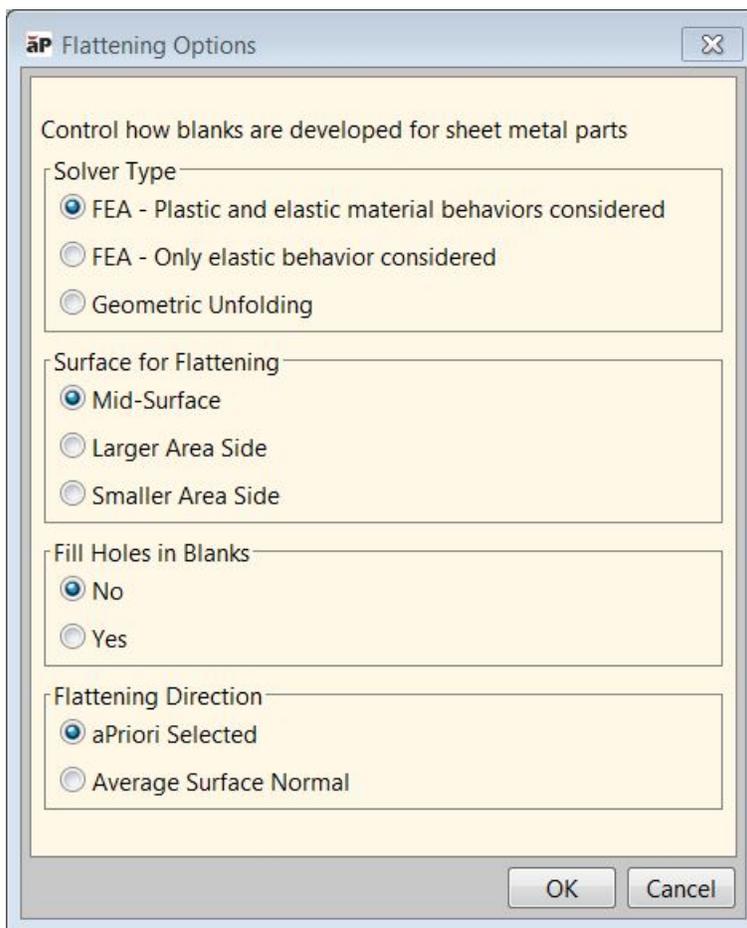
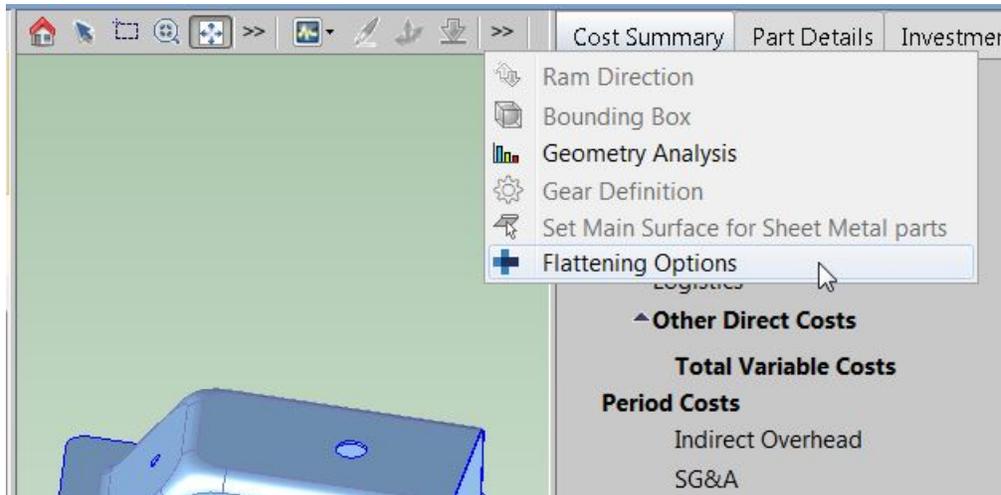
Flattening for Hydroforming

aPriori provides two alternative methods for determining the outline of the flattened part, finite element analysis (FEA)-based flattening and geometric flattening:

- FEA flattening:
 - Analysis is based on a forming simulation which uses a finite element analysis derived from the part’s CAD model and the properties of the selected material.
 - More accurate than geometric flattening for formed and drawn automotive components and similar complex stampings.
 - Generally slower than geometric flattening (very complex parts sometimes require more than one minute to flatten, although the great majority require far less time).
- Geometric flattening:
 - Analysis is based on unfolding of CAD model geometry, and neither takes into account material properties nor simulates the forming process.
 - Accurate for “mostly developable” parts, that is, parts consisting primarily of flat planar surfaces and simple bent or rolled surfaces, with a few small, isolated deformed features like gussets and stiffening beads. These types of parts are common in the agriculture/construction equipment and hi-tech industries.
 - Generally faster than FEA flattening.

FEA flattening is used by default in starting point VPEs. VPE administrators can customize this default with the site variable **flatteningSolverType**.

For a given part, you can override the default flattening method, or configure FEA flattening, with the Flattening Options dialog, which is available from the Viewer toolbar.



The dialog provides the following options:

- **Solver Type:**
 - FEA – Plastic and elastic material behaviors considered: takes into account both the elasticity-related material properties (including Young’s modulus and Poisson’s ratio) and the plasticity-related material properties (including K, the strain-hardening coefficient, N, the strain-hardening exponent, and R, the Lankford parameter, average) . This is the default in starting point VPEs.

- FEA – Only elastic behaviors considered: takes into account only the elasticity-related material properties (including Young’s modulus and Poisson’s ratio). Because only elastic behavior is modeled, blank size estimates are slightly larger with this option than with the “Plastic and elastic” option. Some users prefer this approach as it is slightly more conservative for estimating material usage and costs.
- Geometric Unfolding: Select this if you don’t want to use FEA flattening.

The **Flattening Method** property of the Blank GCD indicates the method used for the most recent geometry extraction. Its possible values are FEA_PLASTIC, FEA_ELASTIC, GEOMETRIC_UNFOLDING.

Geometric Cost Drivers			
Show ▾			
Status	Name	O... Name	Property Result
●	Component	Num Edges	17
●	Base Properties [1]	Num Sharp Corners	-
●	Blank [1]	Straight Length (mm)	1,138.65
●	Blank:2	Flattening Method	FEA_PLASTIC
●	Edge:79	Worst Peninsular Ratio	0.00
●	Edge:80	Worst Peninsular Rati...	0.00
●	Edge:81	Requested	<auto-select>
●	Edge:82	Selected	Blanking / Direct Trimmin...

VPE administrators can customize the default solver type with the site variable **flatteningSolverType**.

- Surface for Flattening: applies to FEA flattening only. FEA flattening proceeds by imposing a mesh on an overall surface of the part. The mesh serves to divide the part into a large but finite number of discrete elements.
 - Mid-Surface: specifies that the mesh should be imposed midway between one side of the part material and the other side of the part material. A mid-surface mesh basically represents the neutral surface of the part. This is the default in starting point VPEs.
 - Larger Area Side: specifies that the mesh should be imposed on the larger-area side of the part material.
 - Smaller Area Side: specifies that the mesh should be imposed on the smaller-area side of the part material.

VPE administrators can customize the default surface for flattening with the site variable **flatteningSurface**.

- Fill Holes in Blanks: applies to FEA flattening only.
 - No: specifies that the mesh (see Surface for Flattening, above) should not be applied to portions of the material surface that will be removed to form a hole. This is the default in starting point VPEs.
 - Yes: specifies that the mesh (see Surface for Flattening, above) should be applied to portions of the material surface that will be removed to form a hole.

VPE administrators can customize the default with the site variable **flatteningFillHoleMethod**.

- Flattening Direction: applies to FEA flattening only.

- aPriori Selected: specifies that the flattening calculation should be based on the ram direction chosen by aPriori—see [Ram Direction GCD](#). This is the default in starting point VPEs.
- Average Surface Normal: specifies that the flattening calculation should be based on a ram direction that is the average direction of the normal to the part's surfaces.

VPE administrators can customize the default flattening direction with the site variable **flatteningDirection**.

VPE Administrators also can customize the FEA flattening behavior with the following site variables:

- **flatteningInitialStrainValue** (0.002 in starting point VPEs): for FEA flattening, specifies the strain present in the material before outside forces and loads are applied.
- **flatteningTimeoutSeconds** (600 seconds in starting point VPEs): determines how long FEA flattening will run before timing out; if FEA flattening times out or fails for any reason, an FEA-failure message appears in the Viewer, and geometric flattening is used instead. A value of 0 indicates no timeout—FEA flattening will run indefinitely.

As mentioned above, FEA flattening takes into account material properties, including the following:

- Density
- Young's Modulus
- Poisson's Ratio, K (strain-hardening coefficient)
- N (strain-hardening exponent)
- R (Lankford parameter, average).

Materials in starting point VPEs specify these properties. If your VPE includes a material that doesn't specify these properties, aPriori uses the following default values based on material type:

Material Type	Young's Modulus (MPa)	Poisson Ratio	K (strain-hardening coefficient, MPa)	N (strain-hardening exponent, MPa)	R (Lankford parameter, average)
Aluminum	69000	0.33	341.1	0.21	0.7
Copper	115000	0.33	317	0.54	0.99
Galvanized Steel	207000	0.28	543	0.21	0.99
Stainless Steel	207000	0.28	1426	0.502	1
Steel	207000	0.28	0.28	479.3	1.345

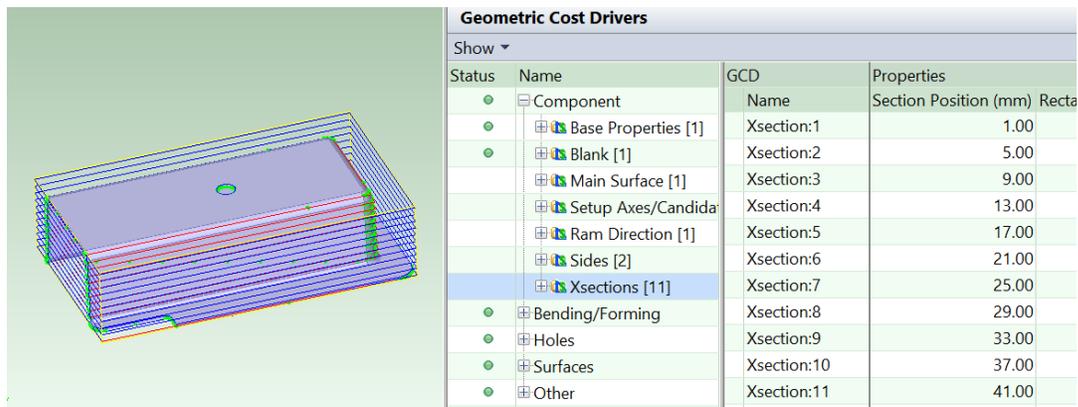
If the material type is not one listed in the table above, the entries for Steel are used.

Xsection GCD

Xsection GCDs represent part cross-sections in planes orthogonal to the ram direction.

By default, aPriori creates up to 11, evenly-spaced Xsections, including Xsections near the top and bottom of the part (the bottom Xsection is half the blank thickness from the bottom of the part, and the top Xsection is half the blank thickness from the top of the part).

Administrators can customize the number of Xsections by setting the site variable **maxNumXsections** (11 in starting point VPEs).



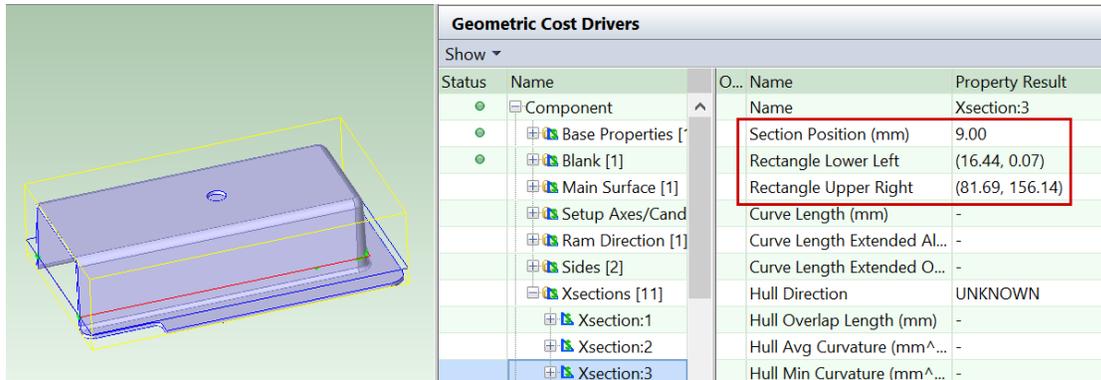
When you select an Xsection, the Viewer displays the following:

- Red line for the rectangle that closely bounds the Xsection.
- Blue line for the corresponding cross-section of the part's bounding box
- Green dots, which mark the Xsection boundary where it doesn't coincide with the bounding rectangle.

The cost model examines the arrangement and widths of the Xsections in order to determine whether deep draw hydroforming is required (see [Process Feasibility for Hydroforming](#)), and in order to determine the number of draws required by deep draw hydroforming (see [Number of Forming Draws](#)).

Important Xsection properties used by the cost model include the following:

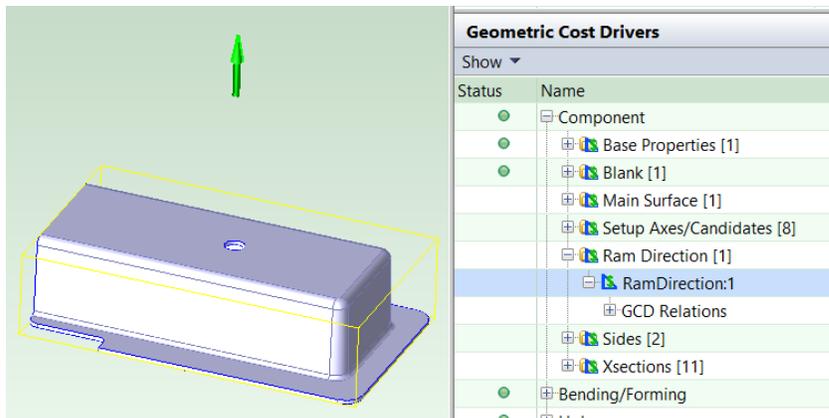
- Section Position: this is the distance between the Xsection and the bottom of the part.
- Rectangle Lower Left and Rectangle Upper Right: these provide coordinates for opposite corners of the Xsection extent, and allow calculation of the extent dimensions in millimeters. **Note:** These values remain millimeter-based regardless of whether you have chosen **Show English Units** from the View menu.



Note that some Xsection properties apply only to the Stretch Forming process group, and so do not have a value in the context of the Hydroforming process group.

Ram Direction GCD

The RamDirection GCD represents the direction from which the bladder approaches the blank (which sits between the bladder and the tool). aPriori chooses a part-relative ram direction as described in [How the Default Ram Direction is Chosen](#). The choice reflects how the part is assumed to be oriented in the hydroforming press. The Ram Direction points up, from the lower tray or punch of the machine toward the bladder.

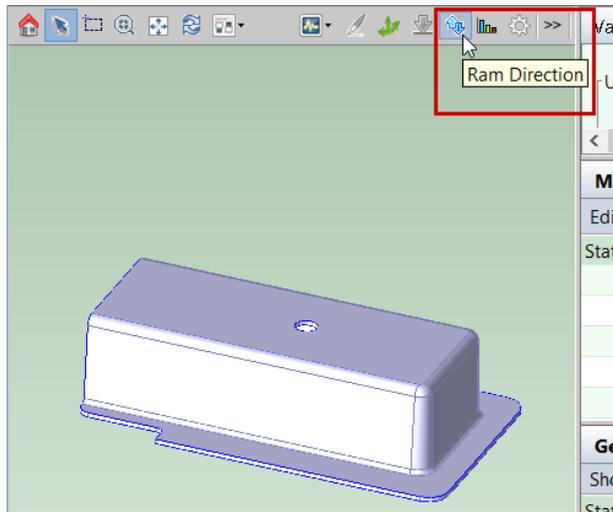


You can override aPriori's choice as described in [Overriding the Default Ram Direction](#). You might need to manually adjust ram direction, for example, in order to ensure that the blank can lie flat on a large area of the tool before forming.

Overriding the Default Ram Direction

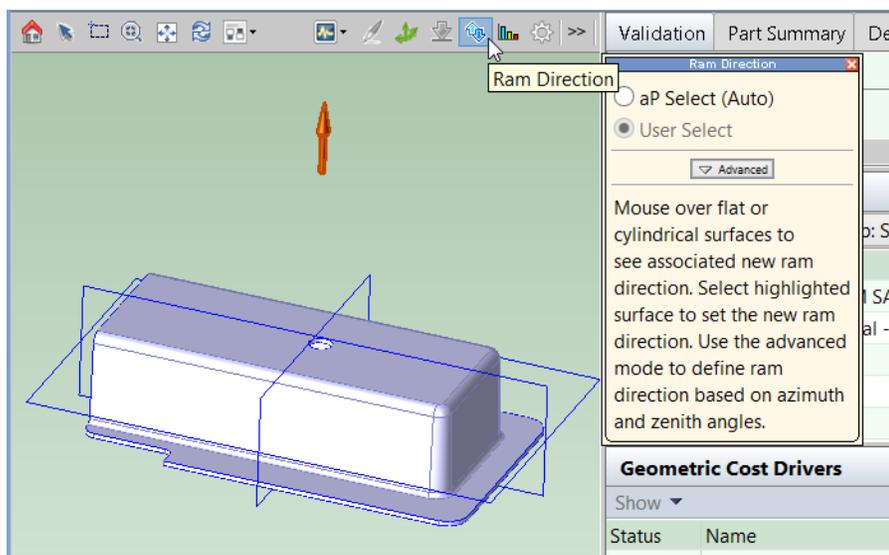
You can override aPriori's choice of ram direction by using the Ram Direction tool, , in the Viewer. Follow these steps:

- 1 Select the Ram Direction tool from the Viewer toolbar.

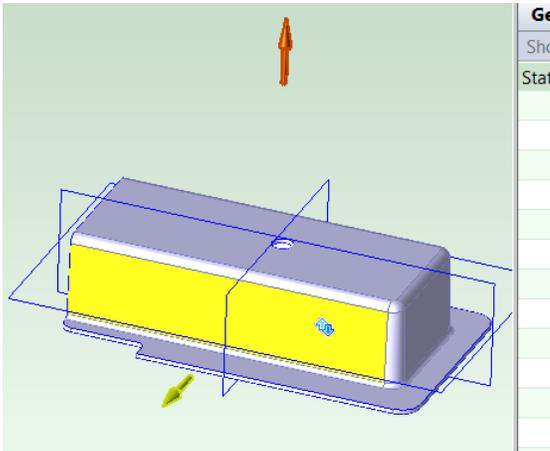


- 2 An orange arrow indicates the ram direction. The arrow points to the region of space *from* which the bladder approaches; the direction in which the bladder moves as it approaches the blank is the opposite of the ram direction.

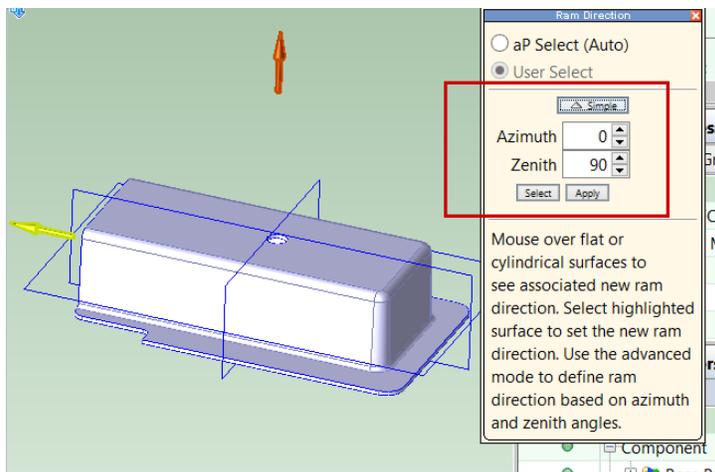
When you hover over a flat or cylindrical surface, the Viewer highlights the surface, and a yellow arrow indicates the candidate ram direction associated with that surface.



Click a highlighted surface to set the new ram direction.



You can also use the Advanced mode of the Ram Direction tool in order to set the ram direction by specifying Azimuth and Zenith.



How the Default Ram Direction is Chosen

In order to choose a ram direction, aPriori identifies a number of candidate directions:

- Direction of each (simple or complex) hole.
- Direction associated with the part's largest, accessible surface

The direction associated with the part's largest accessible surface is a direction that provides the best accessibility to the maximal group of adjacent surfaces that has the following characteristics:

- Group includes the part's largest, accessible surface.
- Every surface in the group is accessible from the same direction.

The direction that provides the best accessibility to such a group is the direction that maximizes the projected area of the surfaces onto a plane perpendicular to the direction.

(Note that a group of adjacent surfaces is a group such that for any pair of surfaces in the group, there is a path from one surface to other that never leaves the group.)

In order to pick the ram direction from among the candidate directions, aPriori also associates such a maximal group of surfaces with each hole. That is, for each hole, it finds the maximal group of adjacent surfaces that has the following characteristics:

- Group includes the surface that contains the hole.
- Every surface in the group is accessible from the same direction.

To select the ram direction, aPiori weighs the following factors for each candidate direction:

- Area of the projection of the candidate's associated surfaces onto a plane perpendicular to the candidate. Larger areas are favored.
- Area of the holes that are parallel to the candidate. Larger areas are favored.
- Projected area of all the part's planar surfaces that are perpendicular to the candidate. Larger areas are favored.
- Area of the surfaces that are *not* in the candidate's associated group. Smaller areas are favored.

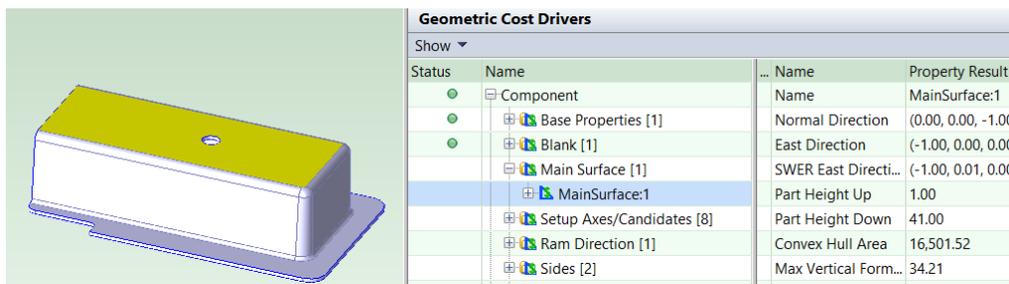
The selected direction actually represents a pair of opposite directions (such as East/West or Up/Down). aPiori selects one element of the pair of opposites based on the following factors:

- Cross-sectional area (parallel to the ram direction) of the part's SER below and above the part. If one area exceeds about twice the other area, the ram direction points towards the smaller volume
- Side-accessible projected area of the flange surfaces that wrap around the part. This is the area of the projection of the outside flanges onto planes that contain the ram direction. If the projected area of one side of the flange surfaces exceeds the projected area of the other side of the flange surfaces by about 10% or more, the side with larger projected area faces the ram direction.

Main Surface GCD

The MainSurface GCD represents a portion of the part that retains a relatively stable orientation relative to the hydroforming press table throughout the forming process. aPiori chooses a main surface as described below. The choice attempts to minimize expensive tooling.

The image below shows the main surface in yellow.



The choice of main surface helps the cost model to identify the part's primary forms, and to determine which of the part's holes can be created prior to forming (during offline blanking or laser cutting).

The MainSurface GCD consists of the group of associated surfaces that has the following characteristics:

- No surface in the group is part of any bend.

- No surface in the group is nearly vertical; that is, the normal to each surface in the group is within 60 degrees of the ram direction (see [Ram Direction GCD](#)).
- Every surface in the group is accessible from the ram direction.

aPriori identifies multiple main-surface candidates that have the above characteristics, and then selects one of the candidates by weighing the following considerations:

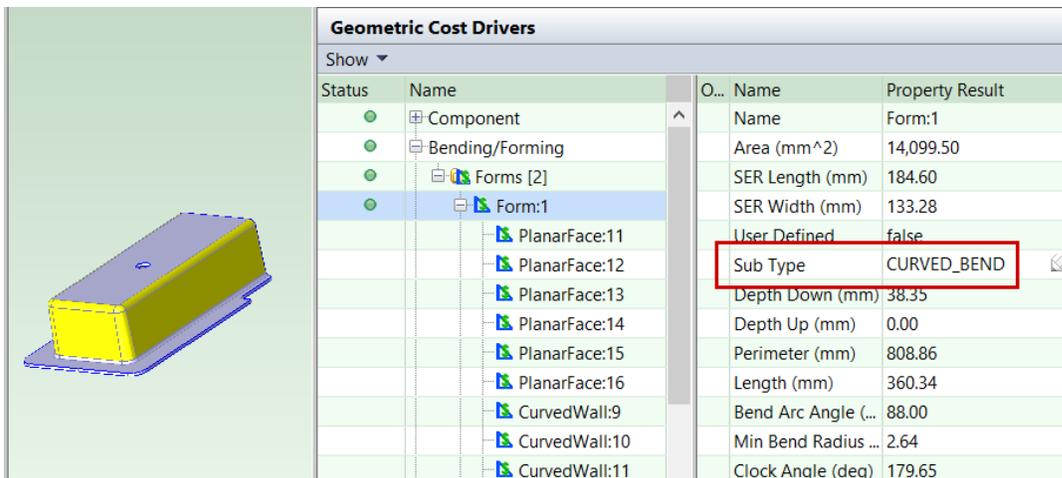
- Height of the surfaces, measured from the bottom of the part bounding box. Higher candidates are favored.
- Area of the surfaces; or, more precisely, the area of the projection of the surfaces—including holes—onto a plane normal to the ram direction. Larger candidates are favored.
- Distance of the surfaces from the centroid of the part. Closer candidates are favored.

Note that surfaces within a given group may be separated into disjoint islands by deformations in the part.

You can override aPriori's choice of ram direction (which affects main surface choice) by using the Ram Direction tool in the Viewer. See [Overriding the Default Ram Direction](#).

Form GCD

The features created by the forming tool in hydroforming are either straight bends or forms. Each form is collection of surfaces, and is classified as either a **CURVED_BEND** or **EMBOSS**. The classification is reflected in the **Sub Type** property listed in the Geometric Cost Drivers pane.



The screenshot shows the Geometric Cost Drivers pane with a 3D model of a bent sheet metal part on the left. The pane is divided into two columns: 'Name' and 'Property Result'. The 'Form:1' group is selected, and its 'Sub Type' property is highlighted with a red box, showing the value 'CURVED_BEND'.

Status	Name	O...	Name	Property Result
●	⊕ Component		Name	Form:1
●	⊖ Bending/Forming		Area (mm^2)	14,099.50
●	⊖ Forms [2]		SER Length (mm)	184.60
●	⊖ Form:1		SER Width (mm)	133.28
	PlanarFace:11		User Defined	false
	PlanarFace:12		Sub Type	CURVED_BEND
	PlanarFace:13		Depth Down (mm)	38.35
	PlanarFace:14		Depth Up (mm)	0.00
	PlanarFace:15		Perimeter (mm)	808.86
	PlanarFace:16		Length (mm)	360.34
	CurvedWall:9		Bend Arc Angle (...)	88.00
	CurvedWall:10		Min Bend Radius ...	2.64
	CurvedWall:11		Clock Angle (deg)	179.65

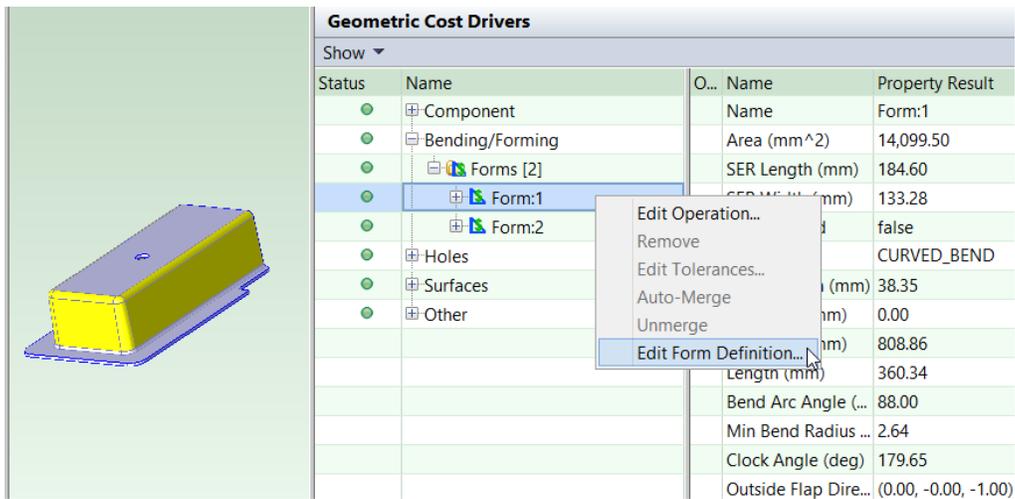
You can override the extracted surface groupings by using the Form Definition dialog, provided you are connected to your part's CAD model. The Form Definition dialog also allows you to change a form's Sub Type from **EMBOSS** to **CURVED_BEND** or vice versa. See [Creating and Editing Form GCDs](#).

Creating and Editing Form GCDs

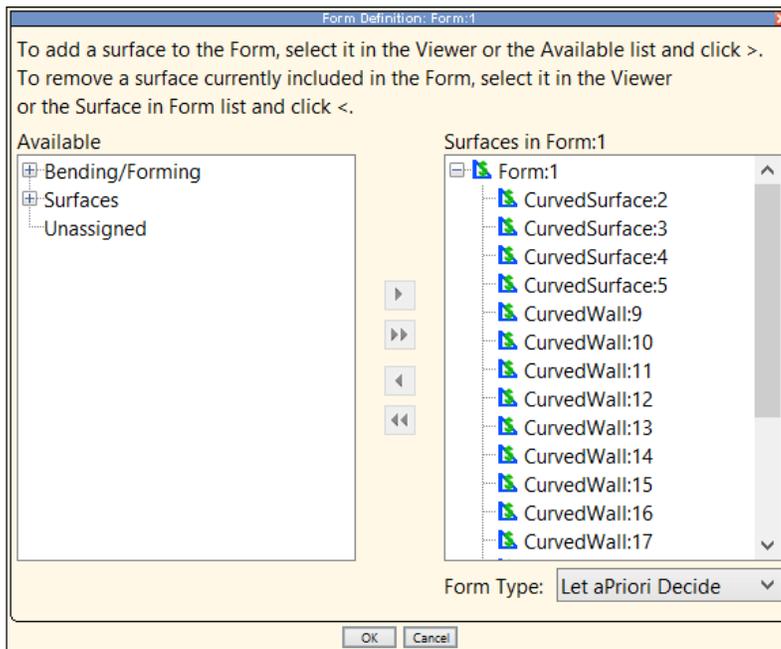
The Form Definition dialog allows you to edit an existing form or create a new form, provided you are connected to your part's CAD model.

To edit an existing form:

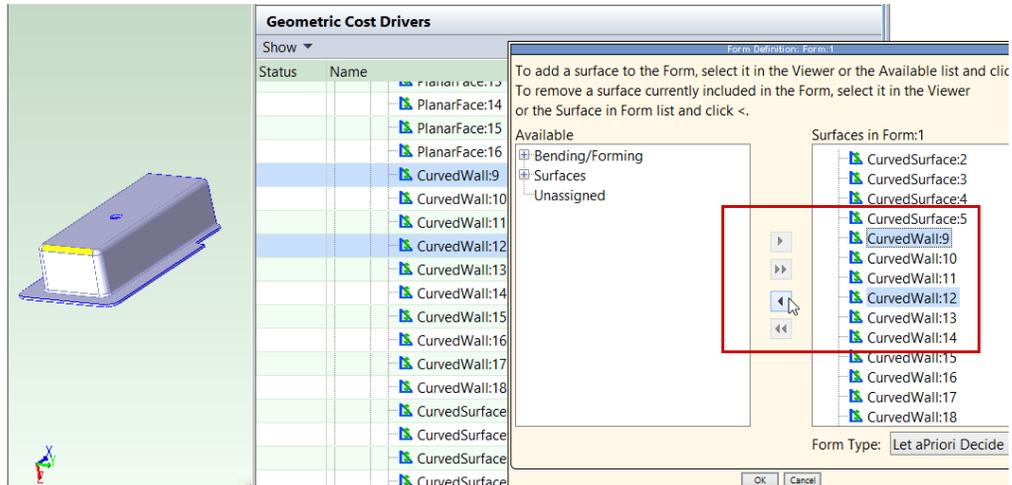
- 1 Right click on the form in the Geometric Cost Drivers pane and select **Edit Form Definition**:



The Form Editor appears:



- 2 Select surfaces in the Viewer or in the dialog, and use the arrows,  and , to move them between the **Available** column and **Surfaces in Form** column. Note that when you select a surface, the opposite surface (directly on the other side of the blank) is automatically selected. Pairs of opposite surfaces are listed in the Geometric Cost Drivers pane under the Parallel relation, under GCD Relations.



You can use the double arrows,  and , to move all a form's surfaces between the **Available** column and **Surfaces in Form** column—select a form GCD in one of the columns and click a double arrow.

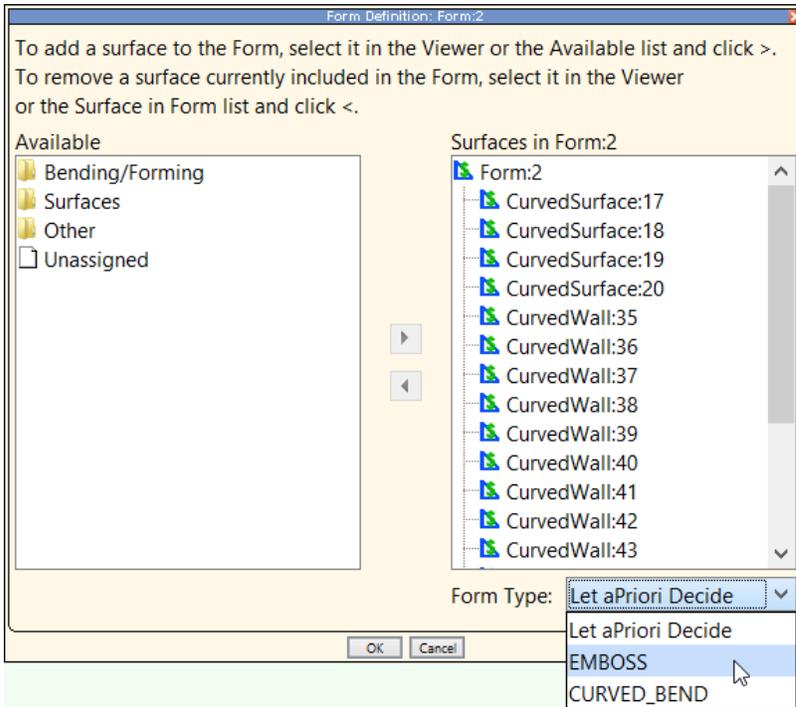
Note that the form must not include any disconnected surfaces, that is, any two surfaces in the form must be connected to one another by a sequence of surfaces all of which are in the form.

3 Re-extract geometry.

To create a new form:

- 1 Click the Form Definition tool, , in the toolbar. The Form Definition dialog appears.
- 2 In the Viewer or in the left pane of the Form Definition dialog, select the forms that you want to include in the new form, and then use the arrow to move them to the **Surfaces in New Form** column.
- 3 Re-extract geometry.

You can change a form's subtype by editing the **Sub Type** property in the Geometric Cost Drivers pane, or by using the Form Definition dialog, provided you are connected to your part's CAD model:

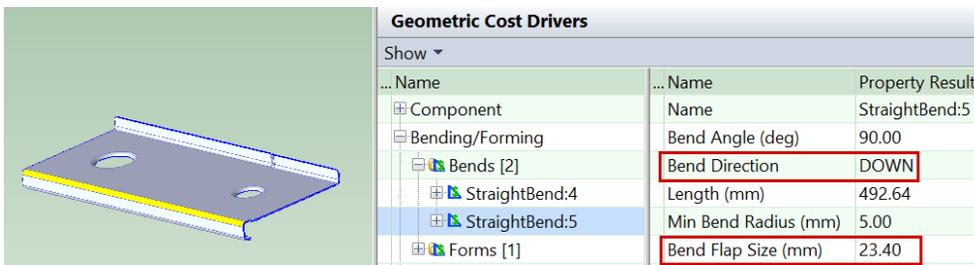


Be sure to re-extract geometry after you change the subtype.

StraightBend GCD

StraightBend GCDs are among the features that can be created by the forming tool in hydroforming (see also [Form GCD](#)). Following are some of the important properties of StraightBend GCDs that play a role in the Hydroforming cost model:

- **Bend Direction:** direction of the bend with respect to the main surface. Possible values include **Up** and **Down**. Up and down bends cannot both be made in the same hydroforming cycle (see [Process Routing for Hydroforming](#)).
- **Bend Flap Size:** The maximum distance between this bend and a neighboring bend or blank contour. Bend Flap Size helps determine whether to assume the use of a blank holder (see [Use Blank Holder](#)), and plays a role in the evaluation of fluid cell feasibility (see [Fluid Cell Feasibility](#)).



Routing and Feasibility for Hydroforming

This section covers the following topics:

- [Process Routing for Hydroforming](#)

- Operation Assignment for Hydroforming
- Process Feasibility for Hydroforming

Process Routing for Hydroforming

The cost model supports two types of hydroforming machines and three alternative blanking processes, so there are six main routings corresponding to the six possible combinations of hydroforming machine type and blanking process:

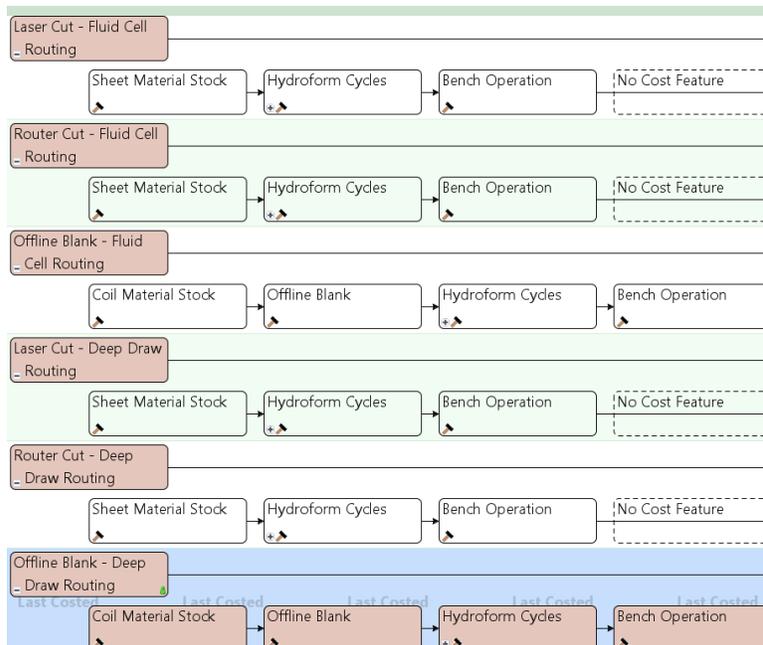
The hydroforming machine types include the following:

- **Fluid Cell:** has a stationary lower tray, on which the tool rests. It can be used to create bends and relatively shallow forms, and often utilizes fully developed blanks. Some undercut geometry is supported by fluid cell machines.
If a part created on a fluid cell machine has both up and down bends, multiple fluid cell cycles are required.
- **Deep Draw:** has a lower tray (on which the tool rests) that can be displaced to create form depth.
If a part's forms are sufficiently deep or form multiple step-like groups, multiple deep draw machine cycles are required. If multiple cycles are required, the part is annealed between cycles—see below.

The blanking processes include the following:

- **2 Axis Router (Router Cut):** cuts nested blanks out of sheet stock. This is modeled by a process in the Sheet Metal process group.
- **Laser Cut:** cuts nested blanks out of sheet stock. This is modeled by a process in the Sheet Metal process group.
- **Offline Blank:** feeds coil stock into a shear press dedicated to blanking, which uses hard tooling to punch out nested blanks.

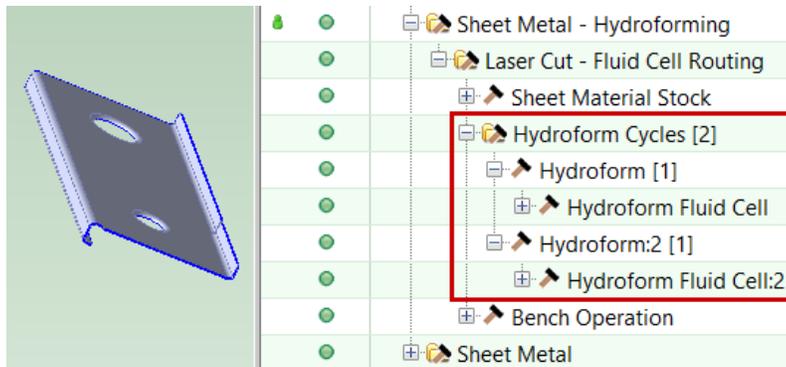
Here are the six main routings:



Each routing includes the following processes:

- One of the following utilization processes:
 - Sheet Material Stock: this is the material utilization process for Laser Cut and Router Cut routings. It performs stock selection, and calculates material utilization and cost.
 - Coil Material Stock: material utilization process for Offline Blank routings. It performs stock selection, and calculates material utilization and cost.
- One of the following blanking processes:
 - Offline Blanking
 - Laser Cut
 - 2 Axis-Router
- Hydroform Cycles: this process has at least one occurrence of the component-level child operation, Hydroform. It has one occurrence of Hydroform for each hydroforming cycle the part requires. (If a fluid cell part has both up and down bends, there may be multiple hydroforming cycles; if a deep draw part has very deep or stepped forms, there may be multiple hydroforming cycles.)

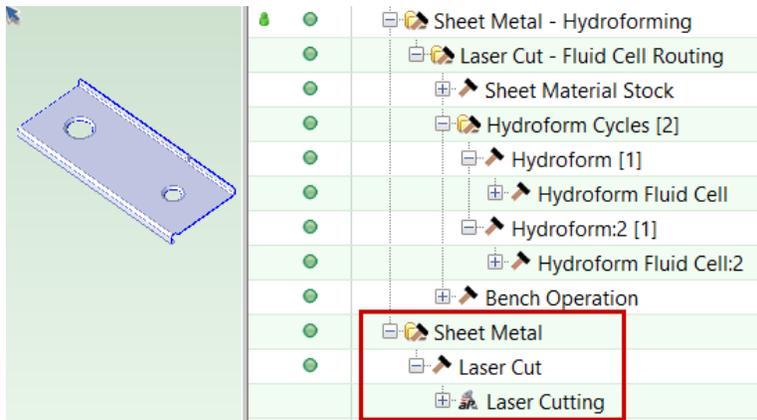
Each occurrence of the Hydroform operation itself has exactly one occurrence of a component-level child operation, either Hydroform Fluid Cell (for fluid cell routings) or Hydroform Deep Draw (for deep draw routings).



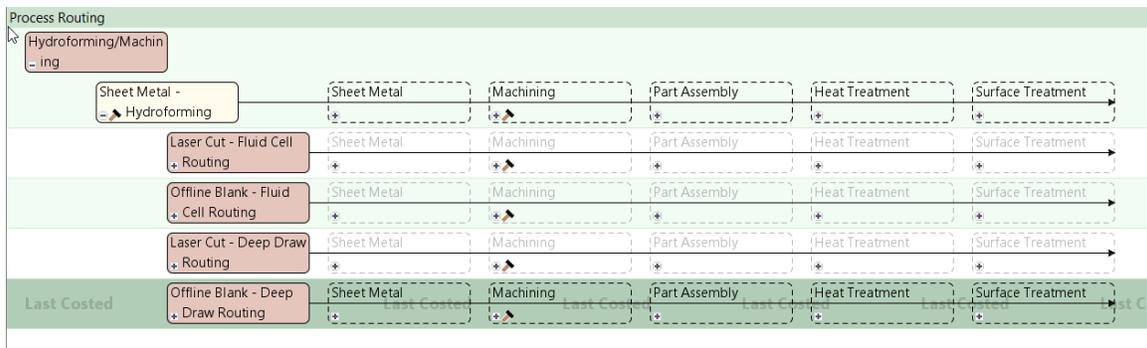
In the example above, the suffix **[2]** in **Hydroform Cycles [2]** indicates the number of occurrences of Hydroform included in the routing. Except for the first occurrence, occurrences of Hydroform Fluid Cell or Hydroform Deep Draw are labelled with a suffix to distinguish different occurrences from one another (as in **Hydroform Fluid Cell:2** in the example above).

- Bench Operation: provides operations for cleaning and inspecting the blank after forming is complete. This process is part of the Sheet Metal—Stretch Forming process group.

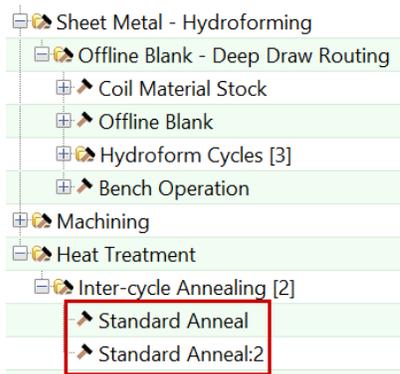
Note that, for 2-Axis Router and Laser Cut routings, the blanking process appears after Hydroform Cycles in the Manufacturing Process pane (see the image below), even though blanking actually occurs before forming. This is because these blanking processes are part of the Sheet Metal process group.



Parts that require multiple draws are typically annealed between draws. This is modeled with the appropriate number of occurrences of the Standard Anneal process in the Heat Treatment process group.



As with blanking processes, the annealing process occurrences appear after Hydroform Cycles in the Manufacturing Process pane.



You can specify additional secondary processes by manually including them.

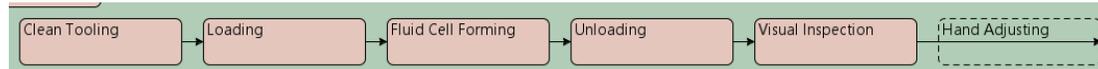
Operation Assignment for Hydroforming

This section covers the following topics:

- Hydroform Operations
- Hole-making Operations
- Edge Trimming

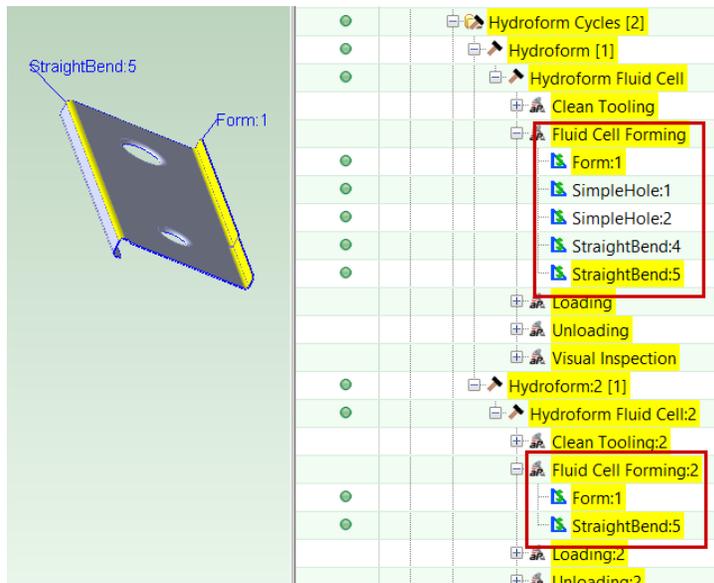
Hydroform Operations

The Hydroform Fluid Cell and Hydroform Deep Draw processes include the following operations:



- **Clean Tooling:** preparing the tool for use by cleaning the tool surface with wet wipes prior to forming. The GCDs it operates on are those that correspond to tool features, including forms, bends, and holes with flanges.
- **Fluid Cell Forming or Deep Draw Forming:** single hydroform machine cycle. In its first occurrence, the GCDs it operates on are those that correspond to tool features, including forms, bends, and holes with flanges. In subsequent occurrences (labelled with a suffix, as in **Fluid Cell Forming:2**), the listed GCDs are those that drive aPriori's decision regarding the number of cycles—see the example below.
- **Loading:** loading the blank onto the hydroforming machine before a machine cycle, including throw pad placement if relevant. The GCDs it operates on are those that correspond to tool features, including forms, bends, and holes with flanges.
- **Unloading:** unloading the blank from the hydroforming machine after a machine cycle, including throw pad removal if relevant. The GCDs it operates on are those that correspond to tool features, including forms, bends, and holes with flanges.
- **Visual Inspection:** inspecting the part after a machine cycle. The GCDs it operates on are those that correspond to tool features, including forms, bends, and holes with flanges.
- **Hand Adjusting:** adjusting or creating a form that can't be fully created by the hydroform machine. This operation must be manually included for a given GCD.

Since all occurrences of Fluid Cell Forming or Deep Draw Forming list the GCDs that drive the number-of-cycles determination, some features fully created in one cycle may be listed under a subsequent cycle. For example, for the part shown below, both **Form:1** (the up bend) and **StraightBend:5** (the down bend adjacent to the main surface) are listed under both occurrences of Fluid Cell Forming, even though one is fully created during the first occurrence and the other fully created during the second occurrence.



Hole-making Operations

Flanged and Countersunk holes are considered to be *formed holes*; they are cut out by the operations of the blanking process and then formed by the Hydroform process.

Non-formed holes are created by the Trim Drill operation sequence on the 5-Axis Mill (in the Machining process group) if *at least one* of the following holds for *at least one* hole:

- Hole has tight tolerance (required tolerance is less than the cost model variable **toleranceLooseThresholdHole**—2mm in starting point VPEs).
- Hole would be distorted by subsequent forming (see below).

Otherwise, non-formed holes are also created by the blanking process.

The cost model determines that a hole would be distorted by subsequent forming if at least one of the following holds:

- Hole is too close to the main surface edge. (The hole bears the **Intersects** relation to the MainSurface GCD, and the relation's **Distance** property is less than the cost model variable **holeToMainSurfaceEdgeProximityThreshold**—3mm in starting point VPEs.)
- Hole intersects an emboss. (The hole bears the **Intersects** relation to a Form of Sub Type **EMBOSS**.)

Edge Trimming

If the part has a nonzero addendum, aPiori adds a secondary Machining operation, Profile Trimming on the 5-Axis Mill, which trims the addendum off. By default, a part has a nonzero addendum if one of the following holds:

- Part is a deep-draw part: the current routing is a deep draw routing.
- Part is a formed fluid-cell part: the current routing is a fluid cell routing and the part has at least one significant form whose **Sub Type** is **EMBOSS**.
- Part has a tight-tolerance edge.

With the PSO **Width of Addendum Added to Blank Size**, users can override the default and specify an addendum width.

For detailed information, see [Width of Addendum Added to Blank Size](#) in Coil Stock Options or [Addendum Added to Blank Size](#) in Sheet Stock Options.

Process Feasibility for Hydroforming

This section covers the following topics:

- [Hydroform Feasibility](#)
- [Fluid Cell Feasibility](#)
- [Deep Draw Feasibility](#)

Hydroform Feasibility

All Hydroform routings require that the part meet *all* the following conditions:

- Part either has at least one Form whose **Sub Type** is **EMBOSS** or **CURVED BEND** or else has at least one StraightBend.
- Part has at least 3 [Xsection GCDs](#).
- Part can be made from stock of uniform thickness (that is, there are no NotSupported GCDs whose **Cause** property has value **DIFFERENT_THICKNESS**).

Fluid Cell Feasibility

Fluid Cell routings are feasible only for parts that have *all* the following characteristics (other parts use Deep Draw routings, if feasible):

- Sufficiently small overall depth-to-width ratio:

Total Form Depth / Lowest Tier Width > 0.55 (in starting point VPEs)

The total form depth (part height, excluding any long, down-bend flaps) divided by the width of the part's lowest tier must be less than the cost model variable **fluidCellFormingRatioThreshold** (0.55 in starting point VPEs). See [Lowest Tier](#) and [Long Down-bend Flaps](#) for details.

- Sufficiently small depth-to-width ratio for the part's top tier:

Top-tier Height / Top-tier Width > 0.55 (in starting point VPEs)

The height of the top tier divided by its width must be less than the cost model variable **fluidCellFormingRatioThreshold** (0.55 in starting point VPEs). The top tier consists of top-most part Xsections of approximately equal width. See [Top Tier](#) and [Xsection Width](#) for details.

This requirement is ignored if there is no significant EMBOSS form. Small stiffening embosses are not considered significant. An emboss form is generally considered significant if it takes up a sufficient fraction of the main surface. In particular, it is significant if both the following hold:

- The emboss's **Min Bend Radius** is greater than 0.
- The product of the emboss's **SER Length** and **SER Width** is greater than the product of the main surface's **Convex Hull Area** and the cost model variable **mainSurfAreaMultiplier**—0.75 in starting point VPEs).

$$\text{Emboss SER Length} * \text{Emboss SER Width} > \text{Main Surface Convex Hull Area} * \text{mainSurfAreaMultiplier}$$

- No bends with excessive curvature:

$$\text{Bend SER Width} / \text{Bend Length} < 0.75 \text{ (in starting point VPEs)}$$

For each form whose **Sub Type** is **CURVED_BEND**, the bend **SER Length** divided by the bend **Length** must be less than the cost model variable **excessiveCurvedFormThreshold** (0.75 in starting point VPEs).

Note that SER width-to-length ratio reflects, roughly, *average* degree of curvature. In the current release, aPiori might fail to detect excessive curvature for bends whose degree of curvature varies a great deal (such as fish-hook-shaped bends).

Deep Draw Feasibility

Deep draw routings are feasible only for parts that have *at least one* of the following characteristics:

- Part has at least one significant Form whose **Sub Type** is **EMBOSS**.

Small stiffening embosses are not considered significant. An emboss form is generally considered significant if it takes up a sufficient fraction of the main surface. In particular, it is significant if both the following hold:

- The emboss's **Min Bend Radius** is greater than 0.
- The product of the emboss's **SER Length** and **SER Width** is greater than the product of the main surface's **Convex Hull Area** and the cost model variable **mainSurfAreaMultiplier**—0.75 in starting point VPEs).

$$\text{Emboss SER Length} * \text{Emboss SER Width} > \text{Main Surface Convex Hull Area} * \text{mainSurfAreaMultiplier}$$

- Part has a high-curvature **CURVED_BEND** form (one that would be excessive for Fluid Cell--see [Fluid Cell Feasibility](#)).

That is, there must be a form whose **Sub Type** is **CURVED_BEND**, and the bend **SER Length** divided by the bend **Length** must be less than the cost model variable **excessiveCurvedFormThreshold** (0.75 in starting point VPEs).

$$\text{Bend SER Width} / \text{Bend Length} < 0.75 \text{ (in starting point VPEs)}$$

Note that SER width-to-length ratio reflects, roughly, *average* degree of curvature. In the current release, aPiori might fail to detect high curvature for bends whose degree of curvature varies a great deal (such as fish-hook-shaped bends).

Top Tier

The top-tier of a part is the maximal set of Xsections such that both the following hold:

- The set includes the top-most Xsection (excluding any Xsection that is less than the blank thickness from the very top of the part).
- All the Xsections in the set have about the same width.

Xsection Width

The width of an Xsection is its smaller dimension orthogonal to the draw direction (calculated from the GCD properties **Rectangle Lower Left** and **Rectangle Upper Right**). The height of the top tier is the number of Xsections times the distance between adjacent Xsection pairs (this distance is the same for all adjacent Xsection pairs of a given part).

Long Down-bend Flaps

The depth in the overall depth-to-width ratio excludes Xsections whose width is less than 4 times the blank thickness, as they are likely to be cross-sections of long, down-bend flaps.

Lowest Tier

The width of the part's lowest tier is the width of the lowest Xsection (excluding any Xsection that is less than the blank thickness from the bottom of the part). The width of an Xsection is its smaller dimension orthogonal to the draw direction (calculated from the GCD properties **Rectangle Lower Left** and **Rectangle Upper Right**).

Material Stock Selection for Hydroforming

This section covers the following topics:

- Material Stock Selection for Offline Blanking Routings
- Material Stock Selection for Laser Cut and Router Cut Routings

Material Stock Selection for Offline Blanking Routings

Offline Blanking assumes the use of virtual coil stock. Stock width depends on the extent of the flat pattern (with addendum, if any) in the direction perpendicular to the coil flow for offline blanking, supplemented by edge margins, as well as (for 2-out parts) part spacing width. See [Coil Width](#) For more information. Stock thickness is based on part thickness.

aPiori assumes the required virtual stock can be obtained at the price per unit weight specified by the material property **Default Cost per KG**.

Note to VPE Administrators: Actual stocks are *not* supported. Do not add actual stock to a Sheet Metal--Hydroforming VPE.

Material Stock Selection for Laser Cut and Router Cut Routings

Laser Cut assumes the use of virtual sheet stock. aPiori assumes the required virtual stock can be obtained at the price per unit weight specified by the material property **Default Cost per KG**.

Note to VPE Administrators: Actual stocks are *not* supported. Do not add actual stock to a Sheet Metal--Hydroforming VPE.

Stock length is given by the cost model variable **standardSheetLength** (2438.4mm in starting point VPEs), provided that this is no less than the length required for a single part (including addendum and trim strips):

$$\text{Minimum Stock Length} = \text{Length of Blank with Addendum} + (2 * \text{Lengthwise Trim Strip Size})$$

If **standardSheetLength** is greater than the minimum stock length, the minimum stock length is used instead.

Similarly, stock width is given by the cost model variable **standardSheetWidth** (1219.2 in starting point VPEs), provided that that this is no less than the width required for a single part (including addendum and trim strips):

$$\text{Minimum Stock Width} = \text{Width of Blank with Addendum} + (2 * \text{Widthwise Trim Strip Size})$$

If **standardSheetWidth** is greater than the minimum stock width, the minimum stock width is used instead.

See [Addendum Added to Blank Size and Trim Strip Sizes](#) for more information.

Trim Strip Sizes

By default, the sizes of the trim strips along the length and width of the stock are the largest trim strip length and width sizes specified by the available machines:

- Default trim strip size along the *length* of the stock sheet is the largest value specified by any machine for the machine property **Sheet Length Trim Strip**.
If no machine specifies a value for this property, the size is specified by the cost model variable **standardLaserCutLeadInAmount** (10mm in starting point VPEs).
- Default trim strip size along the *width* of the stock sheet is the largest value specified by any machine for the machine property **Sheet Width Trim Strip**.
If no machine specifies a value for this property, the size is specified by the cost model variable **standardLaserCutLeadInAmount** (10mm in starting point VPEs).

Users can override the default with the process setup options [Sheet Length Trim Strip—Margin along Material Length](#) and [Sheet Width Trim Strip—Margin along Material Width](#).

Machine Selection for Hydroforming

This section covers the following topics:

- [Hydroform Machine Selection](#)
- [Offline Blank Machine Selection](#)

Hydroform Machine Selection

Machines for the Hydroform process include both deep draw machines and fluid cell machines. aPriori selects the feasible machine of the appropriate type (deep draw or fluid cell—as specified by the machine property **Machine Forming Type**) with the lowest overhead rate. Overhead rate is the sum of the machine properties **Direct Overhead Rate** and **Indirect Overhead Rate**.

The appropriate machine is determined by the current routing. That is, for a deep draw routing, aPriori tries to select a deep draw machine, and for a fluid cell routing, aPriori tries to select a fluid cell machine. (The machine selection code checks for the existence of a node in the current routing with a **deepDrawFormed** attribute. If there is one, aPriori tries to select a deep draw machine. Otherwise, if there is a node in the current routing with a **fluidCellFormed** attribute, aPriori tries to select a fluid cell machine. If the current routing has no node with either attribute, machine selection fails.)

aPriori selects only from preferred machines, if there is a feasible preferred machine of the appropriate type and the cost model variable **usePreferredMachines** is set to **true** (the default in starting point VPEs). If there is no feasible preferred machine of the appropriate type, or if the cost model variable **usePreferredMachines** is set to **false**, aPriori selects from all machines. A machine is preferred if the machine property **isPreferred** (typically displayed as **Is Preferred**) is **true**.

See [Machine Feasibility for Hydroform](#) for more information.

Machine Feasibility for Hydroform

A machine is feasible if it can accommodate all the following part characteristics:

- *Blank dimensions:*
 - For machines with rectangular tables, blank length and width (including any addendum) must be less than the machine properties **Forming Area Length** and **Forming Area Width**, respectively.
 - For machines with circular tables, blank diagonal length (the square root of the sum of the squares of the blank length and width) must be less than the machine property **Forming Area Dia**.
- *Forming depth:* part height must be less than the machine property **Max Draw Depth**.
- *Required forming pressure:* the required forming pressure must be less than the machine property **Max Pressure**.

Required pressure depends on the following

- Material yield strength
- Part's smallest bend radius
- Blank thickness.

See [Required Forming Pressure for Hydroform](#) for more details.

- *Required punch force (deep draw machines only):* for deep draw machines, the required punch force must be less than the machine property **Lower Punch Force**.

Required punch force depends on the following:

- Blank thickness
- Material yield strength
- Blank width (including any addendum)
- Aggregate width of primary forms

See [Required Punch Force for Hydroform](#) for more details.

Required Forming Pressure for Hydroform

The forming pressure required for a given part is calculated as described below.

$$\text{Required Pot Pressure} = 1.2 * \text{Material Yield Strength} * (\text{Blank Thickness} / (\text{Min Bend Radius} + (\text{Blank Thickness} / 2)))$$

Required forming pressure depends on the following:

- Material yield strength: the value of the material property **Tensile Yield Strength**.
- Blank thickness
- Min Bend Radius: the minimum bend radius of any bend or form on the part (or, if there are no bends or forms, the minimum bend radius of any surface on the part).

The constant 1.2 is a safety factor used to ensure that the required pressure is achieved.

Required Punch Force for Hydroform

The punch force required for a given part is calculated as described below.

$$\text{Required Punch Force} = \pi * \text{Blank Thickness} * \text{Material Yield Strength} * ((\text{Blank Width} / \text{Punch Width}) * 0.7)$$

Required punch force depends on the following:

- Blank thickness
- Material yield strength: the value of the material property **Tensile Yield Strength**.
- Blank width: width of the blank, including any addendum (see [Width of Addendum Added to Blank Size](#) for coil stock or [Addendum Added to Blank Size](#) for sheet stock).
- Punch width: the aggregate width of all the part's primary forms (or the part width if there are no primary forms). See [Important Forms for Hydroforming](#) for more information.

Important Forms for Hydroforming

The [Required Punch Force for Hydroform](#) and [Number of Forming Draws](#) for a part depend on the aggregate width of the part's *important* forms.

All of the following are considered *important* forms:

- Forms adjacent to the main surface (that is, forms that bear the **LIES NEAR** relation to the main surface, with a **distance** property of 0)
- The part's *primary* form (see below)
- Other **EMBOSS** forms that intersect the primary form
- Downward **CURVED_BEND** forms that intersect the primary form

A part's *primary form* is the largest-area form for which *all* the following hold:

- Form's **Sub Type** is **EMBOSS**.
- Form is not on the main surface. (That is, it does not bear the **LIES ON** relation to the main surface.)
- Form is adjacent to the main surface. (That is, it bears the **LIES NEAR** relation to the main surface, with a **distance** property of 0.)
- Form depth exceeds blank thickness by a factor greater than the factor looked up by material type in the lookup table **tblMaterialThicknessFactor**.

Material Type	Thickness Factor
Aluminum	10.00
Copper	10.00
Galvanized Steel	10.00
Stainless Steel	10.00
Steel	10.00

Offline Blank Machine Selection

For the Offline Blank process, aPiori selects the feasible machine with the lowest overhead rate, where overhead rate is the sum of the machine properties **Direct Overhead Rate** and **Indirect Overhead Rate**.

If there are multiple lowest-overhead, feasible machines, aPiori chooses the lowest-overhead, feasible machine with the smallest **Shut Height**.

aPiori selects only from preferred machines, if there is a feasible preferred machine and the cost model variable **usePreferredMachines** is set to **true** (the default in starting point VPEs). If there is no feasible preferred machine or if the cost model variable **usePreferredMachines** is set to **false**, aPiori selects from all machines. A machine is preferred if the machine property **isPreferred** (typically displayed as **Is Preferred**) is **true**.

A machine is feasible if it can accommodate all the following:

- Stock dimensions: stock length and width (see [Material Stock Selection for Offline Blanking Routings](#)) must be less than the machine properties **Press Table Length** and **Press Table Width**, respectively.
- Required Press Force: the required press force must be less than the machine property **Press Force**. The required press force depends on the material shear strength and on the blank perimeter and thickness. See [Required Press Force for Offline Blanking](#) for more information.

Required Press Force for Offline Blanking

Required press force for a given part is calculated as follows:

Required Press Force = Required Shear Force + Required Shear Holding Force

Required press force is the sum of the following:

- Required shear force (see formula)
- Required Shear holding force (see formula)

Required Shear Force = Blank Perimeter * Blank Thickness * Material Shear Strength

Required Shear force is the product of the following:

- Blank perimeter
- Blank thickness
- Material yield strength (the value of the material property **Tensile Yield Strength**)

Required Shear Holding Force = Required Shear Force * 0.5

Required shear holding force is assumed to be half the required shear force (see formula above).

Formulas for Hydroforming

This section covers the following topics:

- Yields for Hydroforming
- Material Cost and Utilization for Hydroforming
- Labor and Setup Costs for Hydroforming
- Cycle Time for Offline Blanking
- Cycle Time for the Hydroform Process
- Expendable Tooling Cost for the Hydroform Process

Yields for Hydroforming

These formulas apply to all Hydroforming processes:

Final Yield = Final Output Volume / Local Input Volume

Final yield affects material, labor, and overhead costs per part. It is the fraction of parts created by this process in the current production scenario that will survive as good parts once any secondary processes are completed. That is, final yield is the fraction of parts created by this process that are *not* discarded as scrap parts, either by this process or by a downstream process. Final yield depends on the following:

- Final output volume is the number of parts created by this process that are *not* discarded as scrap parts, either by this process or by a downstream process. It is the product of the annual volume and number of production years, specified in the Production Scenario screen of the Cost Guide.
- Local Input volume (see the formula below). This is the total number of parts produced by this process, including all parts discarded as scrap from this process or downstream processes.

Local Input Volume =
Local Output Volume + Number of Scrap Parts for This Process

Local input volume is the total number of parts produced by this process in the current scenario, including all parts discarded as scrap from this process or downstream processes. It is the sum of the following:

- Local output volume (see the formula below). This is the number of parts produced by this process, excluding parts discarded as scrap by this process, but including parts that are discarded as scrap by downstream processes.
- Number of scrap parts for this process (see the formula below)

Local Output Volume = Final Output Volume + Number of Scrap Parts Downstream

Local output volume is the number of parts produced by this process in the current scenario, excluding parts discarded as scrap by this process, but including parts that are discarded as scrap by downstream processes. It is the sum of the following:

- Final output volume is the number of parts created by this process that are *not* discarded as scrap parts, either by this process or by a downstream process. It is the product of the annual volume and number of production years, specified in the Production Scenario screen of the Cost Guide
- Number of Scrap Parts Downstream. This the number of parts discarded as scrap by downstream processes.

**Number of Scrap Parts for This Process =
(Local Output Volume / Local Good Part Yield) – Local Output Volume**

Number of scrap parts for this process is the number of parts produced by this process in the current scenario that are discarded as scrap by this process, before any downstream process is performed on them. It is a function of the following:

- Local output volume (see the formula above). This is the number of parts produced by this process, excluding parts discarded as scrap by this process, but including parts that are discarded as scrap by downstream processes.
- Local good part yield (specified by the machine property **Good Part Yield**). This is the fraction of parts produced by this process that are not discarded as scrap by this process but may be discarded as scrap by downstream processes.

Material Cost and Utilization for Hydroforming

Material cost for Hydroforming routings is calculated as follows:

Material Cost = Raw Material Cost – Scrap Material Credit – Scrap Part Credit

Material Cost depends on the following:

- Raw material cost: see formula
- Scrap material credit: this is 0 if the setup option [Enable Scrap Material Credit](#) is un-checked (the default in starting point VPEs). Otherwise, it is specified by the formula below.
- Scrap part credit: this is 0 if the setup option [Enable Scrap Part Credit](#) is un-checked (the default in starting point VPEs). Otherwise, it is specified by the formula below.

Raw Material Cost = (Material Cost Per Mass * Rough Mass) / Final Yield

Raw material cost is the cost of material for one part, including the cost of scrap produced during manufacture of the part, as well as the amortized cost of scrapped parts. It depends on the following:

- Material cost per mass: specified by the material property **Cost per KG**.
- Rough mass: see formula.
- Final yield: see [Yields for Hydroforming](#).

Rough Mass = Finish Mass / Utilization

Rough mass depends on the following:

- Finish mass: product of part **Volume** and material **Density**.
- Utilization: calculated by the cost engine. This is part mass divided by stock mass. See [Material Utilization and Part Nesting for Hydroforming](#).

Scrap Material Credit = Material Cost Per Mass * Scrap Cost Percent * Scrap Mass

Scrap material credit is the product of the following:

- Material cost per mass: specified by the material property **Cost per KG**.
- Scrap cost percent: this is 0 if the setup option [Enable Scrap Material Credit](#) is un-checked (the default in starting point VPEs). Otherwise, it is specified as a percentage by the material property **Scrap Cost Percent**.
- Scrap mass: see formula.

Scrap Mass = Rough Mass – Finish Mass

Scrap mass depends on the following:

- Rough mass: see formula.
- Finish mass: product of part **Volume** and material **Density**.

Scrap Part Credit =
(Material Cost per Kg * Scrap Cost Fraction) *
((Number of Scrap Parts + Number of Scrap Parts Down Stream) *
Rough Mass) /
Total Production Volume

Scrap part credit is 0 if the setup option [Enable Scrap Part Credit](#) is set to **false**. Otherwise, it is the product of the following:

- Material cost per mass: specified by the material property **Cost per KG**.
- Scrap cost fraction: this is 0 if the setup option [Enable Scrap Part Credit](#) is un-checked (the default in starting point VPEs). Otherwise, it is specified as a percentage by the material property **Scrap Cost Percent**.
- Number of scrap parts: number of parts discarded as scrap by this process. See [Yields for Hydroforming](#).
- Number of scrap parts down stream: number of parts discarded as scrap by downstream processes. See [Yields for Hydroforming](#).
- Rough mass: see formula.
- Total production volume: specified in the Production Scenario tab of the Cost Guide.

Labor and Setup Costs for Hydroforming

Labor and setup costs are calculated as follows:

Labor Cost = Labor Time * Labor Rate / Final Yield

Labor cost depends on the following:

- Labor time (see formula below)
- Labor rate (specified as a machine property)
- Final yield (see [Yields for Hydroforming](#))

Labor Time = Cycle Time * Number of Operators * Labor Time Standard

Labor time (except for the Cold Storage process) is the product of the following:

- Cycle time (see process-specific Cycle Time formulas)

- Number of operators (specified as a machine property)
- Labor time standard: specified as the machine property **Labor Time Standard**. This multiplier is used to account for otherwise unaccounted for factors that affect labor time, such as operator fatigue or time spent by the operator for cleaning or maintenance.

$$\text{Amortized Batch Setup} = \frac{\text{Setup Time} * (\text{Labor Rate} + \text{Direct Overhead Rate})}{\text{Batch Size}}$$

Batch setup cost per part depends on the following:

- Setup time (specified as the machine property **Setup Time**)
- Labor rate (specified by the machine property **Labor Rate**)
- Direct overhead rate (see [Direct and Indirect Overhead](#))
- Batch size (specified in the **Production Scenario** screen of the Cost Guide)

Cycle Time for Offline Blanking

Cycle time for Offline Blanking is calculated as follows described below.

$$\text{Cycle Time} = \text{Process Time} * \text{Cycle Time Adjustment Factor}$$

Cycle time is the product of the following:

- Process time: unadjusted cycle time for the current process. See the formula below.
- Cycle Time Adjustment Factor: value of the cost model variable **cycleTimeAdjustmentFactor**. This is set to 1 in aPriori starting point VPEs. VPE administrators can change the cost model variable to globally adjust cycle times.

$$\text{Process Time} = \frac{\max(\text{Press Cycle Time}, \text{Material Advance Time})}{\text{Number Concurrent Parts}}$$

Process time is the larger of material advance time and press cycle time (since the coil advances as the machine opens and then closes again. It depends on the following:

- Press cycle time: specified by the machine property **Press Cycle Time**.
- Material advance time: reciprocal of material advance rate, which is interpolated from values looked up by part length in the lookup table **pressMaterialAdvanceRate**. aPriori converts the advance rate from strokes per minute to strokes per second.

ap pressMaterialAdvanceRate	
Part Length (mm)	Strokes Per Minute
0.00	60.00
50.80	60.00
101.60	30.00
152.40	20.00
304.80	10.00
999,999,999.00	5.00

- Number of concurrent parts: see [Material Utilization and Part Nesting for Hydroforming](#).

Cycle Time for the Hydroform Process

The formulas below are used for *each occurrence* of Hydroform Deep Draw or Hydroform Fluid Cell.

Cycle Time = Process Time * Cycle Time Adjustment Factor

Cycle time is the product of the following:

- Process time: unadjusted cycle time for the current process. See the formula below.
- Cycle Time Adjustment Factor: value of the cost model variable **cycleTimeAdjustmentFactor**. This is set to 1 in aPriori starting point VPEs. VPE administrators can change the cost model variable to globally adjust cycle times.

Process Time = Tool Cleaning Time + Loading Time + Forming Time + Unloading Time + Visual Inspection Time + Hand Adjusting Time

Process time is the sum of the following:

- Tool cleaning time: cleaning time is the quotient of the following:
 - Tool surface area (half the part surface area)
 - Cleaning rate (looked up by tool surface area in the lookup table **tblCleanRate**)

ap tblCleanRate	
Component Area (mm ²)	Manual Clean Rate (mm ² / s)
125,000.00	60,000.00
250,000.00	58,000.00
500,000.00	55,000.00
1,000,000.00	50,000.00
5,000,000.00	35,000.00
50,000,000.00	20,000.00
9,999,999,999.999.00	20,000.00

This value is bounded below by the cost model variable **minimmToolCleanTime** (5 seconds in starting point VPEs)

- Loading time: loading time is looked up by stock mass in the lookup table **tblMaterialHandling**.

ap tblMaterialHandling	
Load Time (s)	Weight (kg)
0.00	0.00
8.00	1.00
16.00	5.00
30.00	10.00
38.00	27.00
50.00	999,999,999.00

For fluid cell routings, if a throw pad is in use, this time is supplemented by throw pad application (see formula). A throw pad is used by default for fluid cell routings, but users can override the default with the setup option **Use a Throw Pad**.

- Forming time (see formula)

- Unloading time: unloading time is looked up by stock mass in the lookup table **tblMaterialHandling**. For fluid cell routings, if a throw pad is in use, this time is supplemented by throw pad removal time (see formula). A throw pad is used by default for fluid cell routings, but users can override the default with the setup option **Use a Throw Pad**.
- Visual inspection time: this is specified by the cost model variable **defaultInspectionTime** (45 seconds in starting point VPEs).
- Hand adjusting time: this is the sum of the manual forming times for all GCDs to which the Manual Forming operation is assigned. The manual forming time for a given GCD is the quotient of the following:
 - GCD perimeter
 - Cost model variable **defaultManualFormingRate** (50mm/minute in starting point VPEs)

The Manual Forming operation must be manually assigned to individual GCDs for each desired occurrence of Hydroform Deep Draw or Hydroform Fluid Cell.

Forming Time = Machine Forming Cycle Time / Number of Parts per Tray

Forming time depends on the following:

- Machine forming cycle time (specified by a machine property)
- Number of parts per tray: for deep draw routings, this is 1. For fluid cell routings, this is specified by the cost model variable **defaultNumPartPerFluidCellTray** (1 in starting point VPEs) or by the setup option **Number of Formed Parts per Tray**.

Throw Pad Application Time = Throw Pad Surface Area / Throw Pad Application Rate

Throw pad application (which supplements loading time for fluid cell routings if a throw pad is in use) time depends on the following:

- Throw pad surface area: a rectangular throw pad is assumed, where each throw pad dimension (length or width) is the corresponding blank dimension extended by the cost model variable **throwPadAddendum** (75mm in starting point VPEs).
- Throw pad application rate: specified by cost model variable **throwPadApplicationRate** (3000mm²/sec in starting point VPEs).

Throw Pad Removal Time = Throw Pad Surface Area / Throw Pad Removal Rate

Throw pad removal (which supplements unloading time for fluid cell routings if a throw pad is in use) time depends on the following:

- Throw pad surface area: a rectangular throw pad is assumed, where each throw pad dimension (length or width) is the corresponding blank dimension extended by the cost model variable **throwPadAddendum** (75mm in starting point VPEs).
- Throw pad removal rate: specified by cost model variable **throwPadRemovalRate** (3000mm²/sec in starting point VPEs).

Expendable Tooling Cost for the Hydroform Process

**Expendable Tooling Cost per Part =
Cleaning Wipes Quantity * Cleaning Wipes Cost Each**

Expendable tooling cost for each draw is the product of the following:

- Cleaning wipes quantity: this is one wipe for every 4 square meters of tool surface area. Tool surface area is half the part surface area.
- Cleaning wipes cost each: cost per wipe is specified by the tool shop variable `consumableMaterial_CleaningWipes`.

User Inputs for Hydroforming

This section covers the following topics:

- Sheet Metal – Hydroforming Options
- Hydroform Fluid Cell Options
- Hydroform Cycles Option
- Coil Material Stock Options
- Sheet Material Stock Options
- Hydroform Options
- Offline Blank Options

Sheet Metal – Hydroforming Options

The Sheet Metal – Hydroforming node provides the following setup options:

- Number of Forming Draws
- Enable Scrap Material Credit
- Enable Scrap Part Credit

Number of Forming Draws

Specifies the number of draws, that is, the number of occurrences of Hydroform Deep Draw or Hydroform Fluid Cell.

For Fluid Cell, by default, if the part has both up and down bends, the number of draws is 2. Otherwise the default number of draws for Fluid Cell is 1.

For Deep Draw, by default, if the part's Xsections form step-like groups, the number of draws is the number of such groups.

Otherwise, the default number of draws for Deep Draw is based on the aggregate width of the part's important forms (see [Important Forms for Hydroforming](#)) and on the form width reduction produced by each draw, as specified by the lookup table `drawReductionPercentage`, with an adjustment applied for high-strength materials (see [High Strength Material Derate Percentage](#)).

See [Number of Draws Based on Number of Step-like Xsection Groups](#). and [Number of Draws Based on Aggregate Width of Important Forms](#) for more information.

You can override the default with this option.

Enable Scrap Material Credit

By default in starting point VPEs, the cost model assumes that material scrap (such as trim scrap) is *not* sold for credit. Administrators can customize the default with the cost

model variable **enableScrapMaterialCredit** (**false** in starting point VPEs). With this setup option, users can override the default on a per-part basis.

Enabling scrap material credit increases material utilization and decreases material cost. The credit rate is specified as a percentage of the material rate by the material property **Scrap Cost Percent**. See [Material Cost and Utilization for Hydroforming](#).

Enable Scrap Part Credit

By default in starting point VPEs, the cost model assumes that the material from scrapped parts is *not* sold for credit. Administrators can customize the default with the cost model variable **enableScrapPartCredit** (**false** in starting point VPEs). With this setup option, users can override the default on a per-part basis.

Enabling scrap part credit increases material utilization and decreases material cost. This includes credit for parts scrapped by this process as well as by downstream processes. The credit rate is specified as a percentage of the material rate by the material property **Scrap Cost Percent**. See [Material Cost and Utilization for Hydroforming](#).

Hydroform Fluid Cell Options

The Hydroform Fluid Cell node provides the following options:

- Use Blank Holder
- Number of Formed Parts per Tray
- Use a Throw Pad

Use Blank Holder

This option helps determine whether aPriori assumes the use of a blank holder during forming, which affects hard tooling costs—see [Tooling for Hydroforming](#).

By default, aPriori includes the cost of a blank holder if the *skirt length* exceeds a threshold:

Skirt Length > Skirt Length Limit (38.1 in starting point VPEs)

The skirt length is the maximum downward depth or flap length of any form or straight bend. The threshold is specified by the cost model variable **skirtLengthLimit** (38.1mm in starting point VPEs).

In other words, by default, aPriori includes the cost of a blank holder if either of the following holds:

- The **Depth Down** of some form (of type **EMBOSS** or **CURVED_BEND**) exceeds the cost model variable **skirtLengthLimit** (38.1mm in starting point VPEs).
- The **Flap Length** of some straight bend exceeds the cost model variable **skirtLengthLimit** (38.1mm in starting point VPEs).

You can override the default with this option.

Number of Formed Parts per Tray

By default in starting point VPEs, the hydroform process creates only one part at a time. VPE Administrators can customize the default for fluid cells parts with the cost model variable **defaultNumPartPerFluidCellTray**. End users can override the default for individual

fluid cell parts with this setup option. The number of parts per tray affects cycle time—see [Cycle Time for the Hydroform Process](#).

If you override the default, enter a value that doesn't exceed the maximum number of parts that fit on the tray. (To calculate the maximum, the cost model assumes that the parts are arranged in a rectangular grid, with all parts oriented the same way. For machines with a rectangular tray, the cost model further assumes that each blank's SER length or SER width is aligned with the tray length—whichever is more efficient.)

Use a Throw Pad

By default, the cost model assumes the use of a throw pad covering the blank, which affects loading and unloading time—see [Cycle Time for the Hydroform Process](#). Users can override the default with this setup option, and specify that no throw pad is used.

Hydroform Cycles Option

The Hydroform Cycles node provides the following option:

- High Strength Material Derate Percentage

High Strength Material Derate Percentage

This setup option can affect the number of draws, that is, the number of occurrences of the Hydroform Deep Draw operation required to produce a given form. See [Number of Forming Draws](#) and [Number of Draws Based on Aggregate Width of Important Forms](#).

By default, this is specified by the cost model variable **defaultMatIDeratePercent** (10% in starting point VPEs). Use this to override the default behavior for parts that use high-strength material. Enter a value between 0% and 50%. Increasing this value can increase the number of draws.

High-strength material is defined as material with a tensile yield strength of 344.74 Mpa in starting point VPEs. VPE administrators can customize this threshold with the cost model variable **highStrengthMatThreshold**. (344.74MPa in starting point VPEs).

Number of Draws Based on Number of Step-like Xsection Groups

If the part's Xsections form step-like groups, the number of draws (see [Number of Forming Draws](#)) is the number of such groups. An Xsection ends one step-like group and starts another step-like group if its SER area is a sufficiently small fraction of the SER area of the immediately preceding Xsection (going from bottom to top). What counts as a sufficiently small fraction is specified by the cost model variable **percentChangeBetweenValidSteps** (0.65 in starting point VPEs). The number of draws is 1 + the number of Xsections that start a step-like group in this sense (the part's top-most Xsection is not included for this purpose).

Number of Draws Based on Aggregate Width of Important Forms

If the part's Xsections don't form step-like groups, the number of draws (see [Number of Forming Draws](#)) is calculated based on the aggregate width of the primary forms (see [Important Forms for Hydroforming](#)), and on the form width reduction produced by each draw. The lookup table **drawReductionPercentage** lists the percentage of the pre-draw width that remains after a given draw (that is, initial draw, first subsequent draw, second subsequent draw, or third subsequent draw) for a given material thickness. For example, for the second subsequent draw of 1-inch-thick material, the table lists 81%. This means

that the second subsequent draw (for 1-inch-thick material) results in a width that is 81% of the form's width immediately prior to that occurrence of the draw operation.

For high-strength materials, the percentage listed in the lookup table is itself increased by 10 percent, by default in starting point VPEs. For example, for the second subsequent draw of 1-inch-thick material, the table value of 81% is increased by 10 percent to 81.8%, for high-strength material. VPE administrators can customize the 10 percent default with the cost model variable **defaultMatlDeratePercent**. You can override the default on a per-part basis with the PSO [High Strength Material Derate Percentage](#).

High-strength material is defined as material with a tensile yield strength of 344.74 Mpa in starting point VPEs. VPE administrators can customize this threshold with the cost model variable **highStrengthMatlThreshold**. (344.74MPa in starting point VPEs).

Coil Material Stock Options

The Coil Material Stock process provides the following setup options:

- Evaluate Strip Nesting Layout: 1 Out
- Evaluate Strip Nesting Layout: 2 Out, Non-interlocking, Mirrored
- Evaluate Strip Nesting Layout: 2 Out, Non-interlocking, Rotated
- Evaluate Strip Nesting Layout: 2 Out, Interlocking, Mirrored
- Evaluate Strip Nesting Layout: 2 Out, Interlocking, Rotate
- Blank Pitch
- Coil Width
- Edge Margin Width
- Part Spacing Width
- Width of Addendum Added to Blank Size

Evaluate Strip Nesting Layout: 1 Out

By default aPriori evaluates the cost of performing Offline Blanking with a 1-out layout only. You can override the default, and tell aPriori to evaluate the cost of other layouts as well by selecting **Yes** for one or more of the Evaluate Strip Nesting Layout... setup options. aPriori will choose the lowest-cost layout.

If you do not want a 1-out layout to be considered, select **No** for this setup option.

If you are using Rectangular Nesting (see [Material Utilization and Part Nesting for Hydroforming](#)), and you select **Yes** for this option, all Evaluate Strip Nesting Layout: 2 Out... setup options must be set to **No** (or the part will fail to cost).

Evaluate Strip Nesting Layout: 2 Out, Non-interlocking, Mirrored

By default aPriori evaluates the cost of performing Offline Blanking with a 1-out layout only. You can override the default, and tell aPriori to evaluate the cost of other layouts as well by selecting **Yes** for one or more of the Evaluate Strip Nesting Layout... setup options. aPriori will choose the lowest-cost layout.

Select **Yes** for this setup option to include evaluation of a 2-out, non-interlocking, mirrored layout. See [Interlocking and Non-interlocking Layouts](#).

If you are using Rectangular Nesting (see [Material Utilization and Part Nesting for Hydroforming](#)), and you select **Yes** for this option, Evaluate Strip Nesting Layout: 1 Out must be set to **No** (or the part will fail to cost).

Evaluate Strip Nesting Layout: 2 Out, Non-interlocking, Rotated

By default aPriori evaluates the cost of performing Offline Blanking with a 1-out layout only. You can override the default, and tell aPriori to evaluate the cost of other layouts as well by selecting **Yes** for one or more of the Evaluate Strip Nesting Layout... setup options. aPriori will choose the lowest-cost layout.

Select **Yes** for this setup option to include evaluation of a 2-out, non-interlocking, rotated layout. See [Interlocking and Non-interlocking Layouts](#).

If you are using Rectangular Nesting (see [Material Utilization and Part Nesting for Hydroforming](#)), and you select **Yes** for this option, Evaluate Strip Nesting Layout: 1 Out must be set to **No** (or the part will fail to cost).

Evaluate Strip Nesting Layout: 2 Out, Interlocking, Mirrored

By default aPriori evaluates the cost of performing Offline Blanking with a 1-out layout only. You can override the default, and tell aPriori to evaluate the cost of other layouts as well by selecting **Yes** for one or more of the Evaluate Strip Nesting Layout... setup options. aPriori will choose the lowest-cost layout.

Select **Yes** for this setup option to include evaluation of a 2-out, interlocking, mirrored layout. See [Interlocking and Non-interlocking Layouts](#).

If you are using Rectangular Nesting (see [Material Utilization and Part Nesting for Hydroforming](#)), and you select **Yes** for this option, Evaluate Strip Nesting Layout: 1 Out must be set to **No** (or the part will fail to cost).

Evaluate Strip Nesting Layout: 2 Out, Interlocking, Rotate

By default aPriori evaluates the cost of performing Offline Blanking with a 1-out layout only. You can override the default, and tell aPriori to evaluate the cost of other layouts as well by selecting **Yes** for one or more of the **Evaluate Strip Nesting Layout...** setup options. aPriori will choose the lowest-cost layout.

Select **Yes** for this setup option to include evaluation of a 2-out, interlocking, mirrored rotated. See [Interlocking and Non-interlocking Layouts](#).

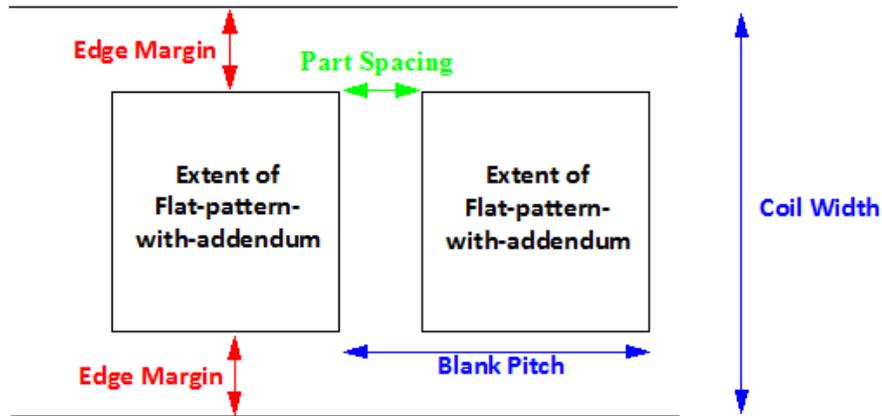
If you are using Rectangular Nesting (see [Material Utilization and Part Nesting for Hydroforming](#)), and you select **Yes** for this option, Evaluate Strip Nesting Layout: 1 Out must be set to **No** (or the part will fail to cost).

Blank Pitch

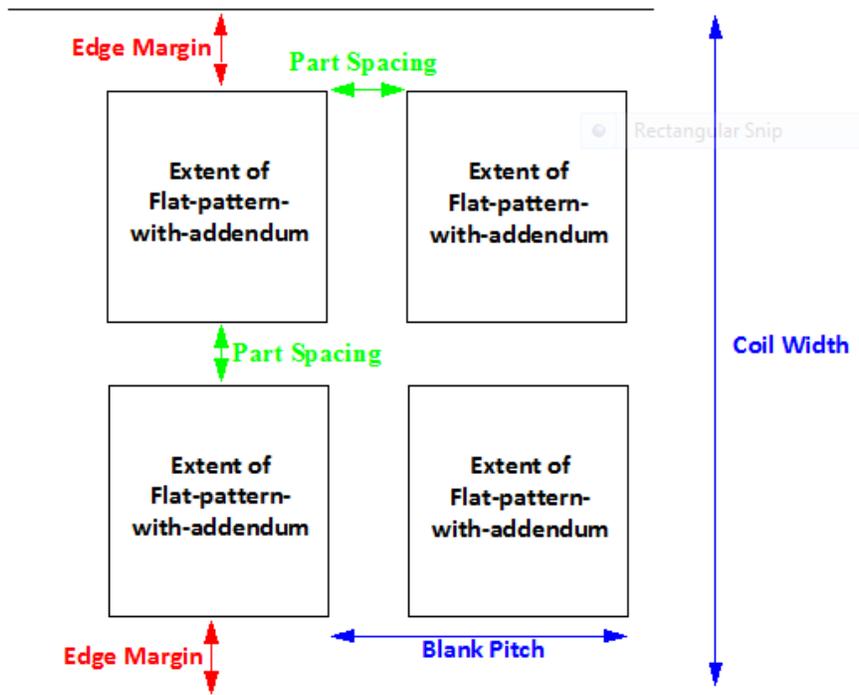
Blank pitch is the extent of the flat pattern (with addendum, if any) along the direction of coil flow for offline blanking, supplemented by the part spacing width. By default, this is calculated using aPriori's strip nesting algorithm. The default value is the sum of the following:

- Extent of the flat pattern (with addendum, if any) in the direction of coil flow, when best nested (as determined by the aPriori strip nesting algorithm)
- Part Spacing Width

1-Out Layout Edge Margins and Part Spacing



2-Out Layout Edge Margins and Part Spacing



You can override the default with this option, which affects both material utilization and tooling sizes and costs. It is your responsibility to ensure that the overrides have legal results, for example, that the resulting blanks do not overlap.

Select one of the following options:

- Default: calculated by aPiori (as described above)
- User Override: enter a value in millimeters or inches that is greater than or equal to 1.0 mm.

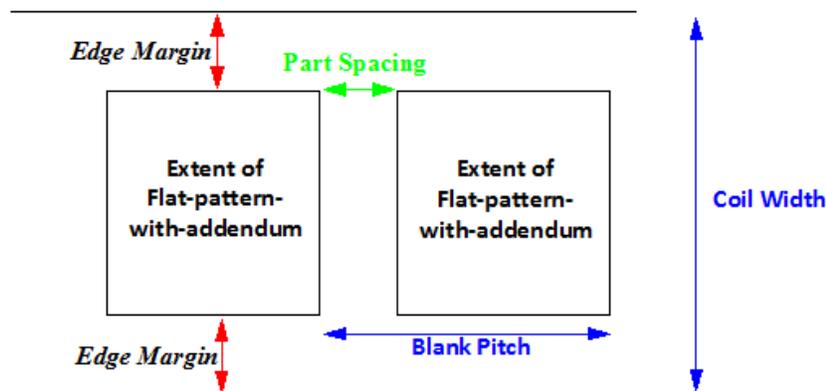
Coil Width

Coil width is determined by the extent of the flat pattern (with addendum, if any) in the direction perpendicular to the coil flow for offline blanking, supplemented by edge margins, as well as (for 2-out parts) part spacing width. By default, this is calculated using aPiori's strip nesting algorithm.

The default value for a 1-out layout is the sum of the following:

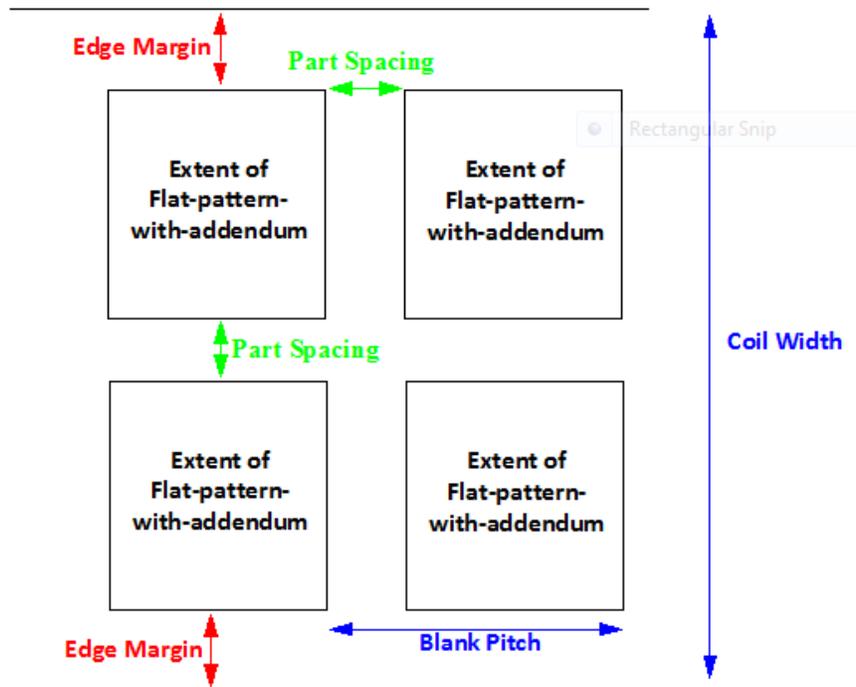
- Extent of the flat pattern (with addendum, if any) in the direction perpendicular to the coil flow, when best nested (as determined by the aPiori strip nesting algorithm)
- 2 * Edge Margin Width

1-Out Layout Edge Margins and Part Spacing



The default value for a 2-out layout is the sum of the following:

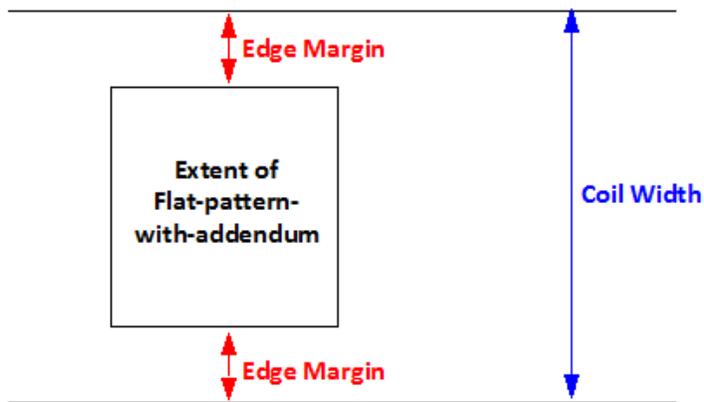
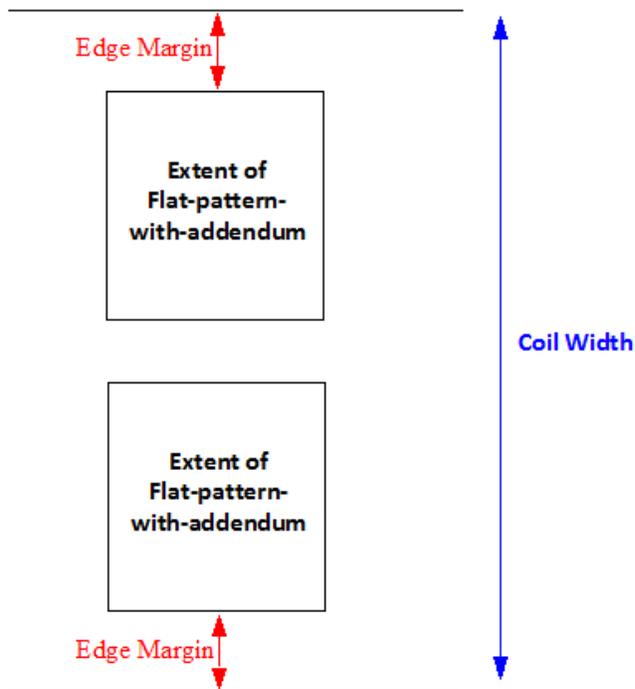
- 2 * Extent of the flat pattern (with addendum, if any) in the direction perpendicular to the coil flow, when best nested (as determined by the aPiori strip nesting algorithm)
- 2 * Edge Margin Width
- Part Spacing Width

2-Out Layout Edge Margins and Part Spacing

You can override the default with this option, and specify a larger coil width. Coil width affects material utilization and tooling sizes and costs.

Edge Margin Width

This option specifies the width of the extra space between the coil edge and the flat pattern. In aPriori starting point VPEs, the default value is 1.5 times the material thickness. VPE administrators can customize the thickness multiplier with the cost model variable `defaultEdgeMarginWidthMultiplier`.

1-Out Layout Edge Margins*2-Out Layout Edge Margins*

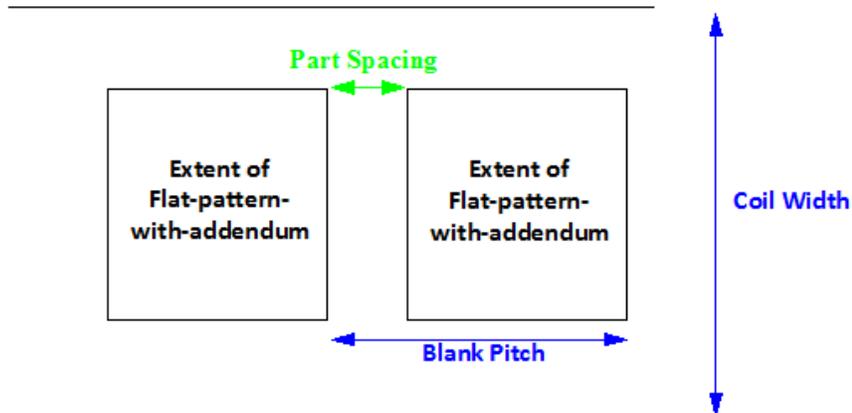
Select one of the following options:

- Default: in aPriori starting point VPEs, the default value is 1.5 times the material thickness. VPE administrators can customize the thickness multiplier with the cost model variable **defaultEdgeMarginMultiplier**.
- User Override: enter a value greater than or equal to 0.

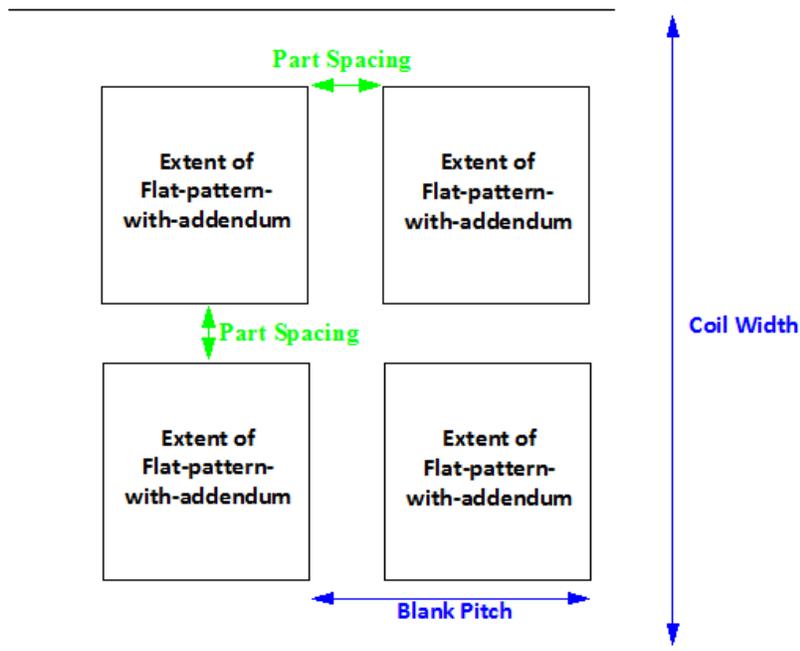
Part Spacing Width

Width of extra space between adjacent blanks. This value specifies both the distance between blanks in the coil pitch direction, as well as the distance in the coil width direction between rows of a 2-out layout. In aPiori starting point VPEs, the default value is 1.5 times the material thickness. VPE administrators can customize the thickness multiplier with the cost model variable `defaultPartSpacingMultiplier`

1-Out Layout Part Spacing



2-Out Layout Part Spacing



Select one of the following options:

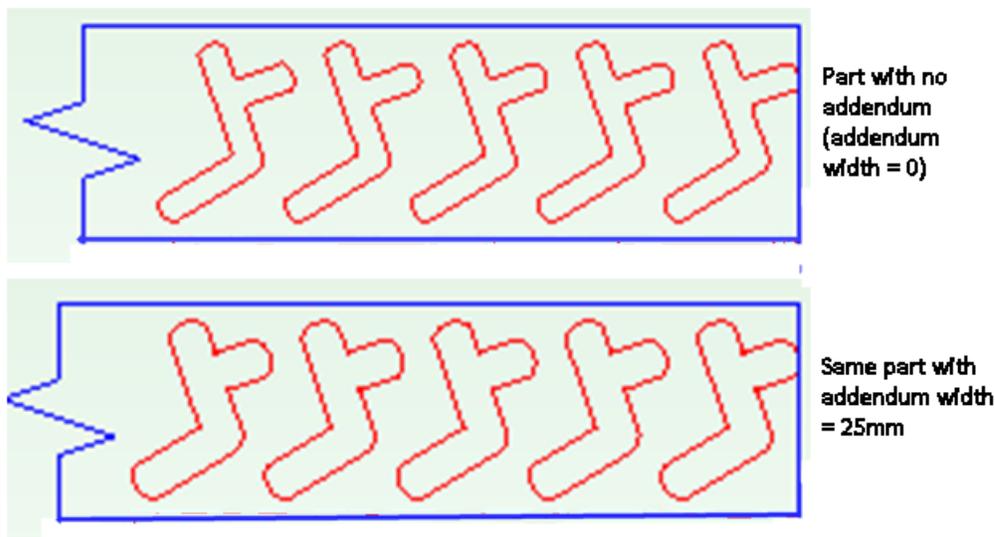
- Default: in aPriori starting point VPEs, the default value is 1.5 times the material thickness. VPE administrators can customize the thickness multiplier with the cost model variable **defaultPartSpacingMultiplier**.

User Override: enter a value greater than or equal to 0.

Width of Addendum Added to Blank Size

This is the width of an offset to be added all around the perimeter of the flattened part. You can enter a non-zero value in order to do one of the following:

- Add additional material for the purpose of holding the blank during the forming process, which is subsequently trimmed away.
- Compensate for cases in which aPriori underestimates flattened blank size, for example, for highly deformed parts.



Select one of the following options:

- Let aPriori Decide: this is the default, computed based on form depth and edge tolerance, using the lookup table **blankAddendumWidth**. See below.
- No Addendum: addendum size is set to 0.
- User Override: enter a value greater than or equal to 0.

If you choose Let aPriori Decide, aPriori adds addendum in all the following cases:

- Deep-draw part: the current routing is a deep draw routing (the CSL code checks for the existence of a node in the current routing with a **deepDrawFormed** attribute).
- Formed Fluid-cell part: the current routing is a fluid cell routing and the part has at least one significant form whose **Sub Type** is **EMBOSS**. An emboss form is considered significant if it takes up a sufficient fraction of the main surface (that is, if the product of the emboss's **SER Length** and **SER Width** is greater than the product of the main surface's **Convex Hull Area** and the cost model variable **mainSurfAreaMultiplier**—0.75 in starting point VPEs).
- Tight-tolerance edge: at least one blank edge has tolerance less than the cost model variable **looseEdgeToleranceThreshold** (2mm in starting point VPEs).

The width of the addendum is looked up by aggregate form depth (*excluding* forms of type **CURVED_BEND**) in the lookup table **blankAddendumWidth**. For folded parts (those with no significant emboss) that have tight tolerance, aPriori chooses the smallest addendum listed in **blankAddendumWidth**.

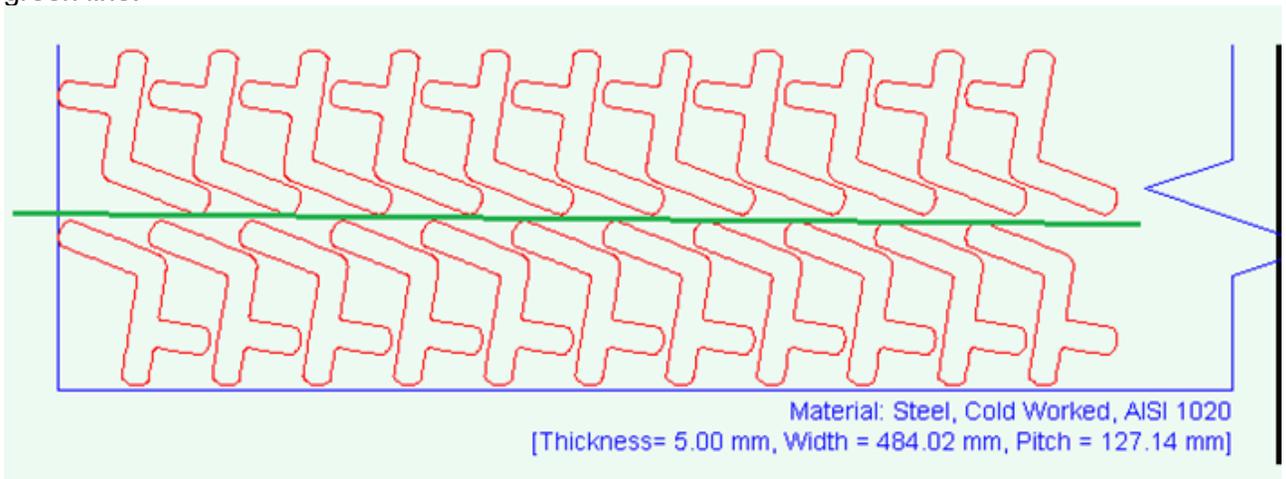
aP blankAddendumWidth	
Addendum Width (mm)	Total Form Depth (mm)
6.00	25.00
12.00	50.00
18.00	75.00
24.00	100.00
30.00	125.00
36.00	150.00
42.00	175.00
48.00	200.00
54.00	225.00
60.00	250.00
66.00	275.00
72.00	300.00
80.00	325.00

Aggregate form depth is the sum of the depths of all forms whose **Sub Type** is *not* **CURVED_BEND**. Each form's depth is the value of the property **Depth Up** or **Depth Down**, whichever is nonzero.

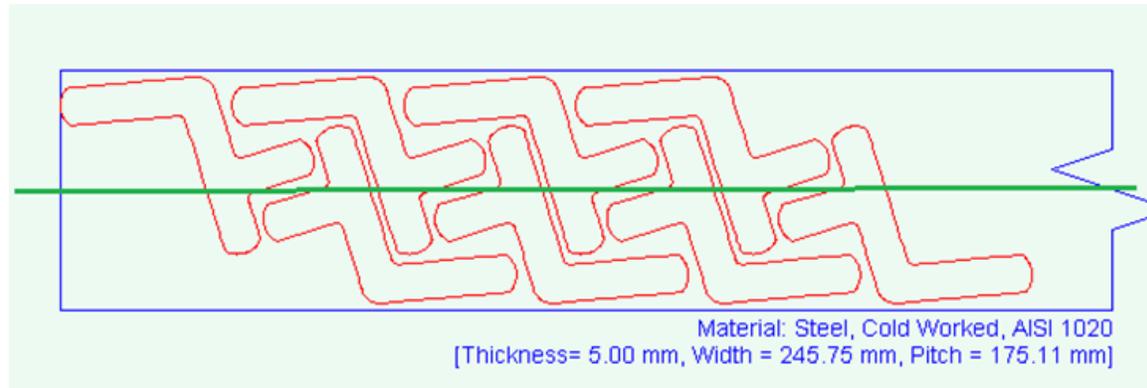
Note that when an addendum is present (whether calculated or user-specified), aPriori adds a secondary Machining operation, Profile Trimming on the 5-Axis Mill, which trims the addendum off. If no addendum is present, Blanking is assumed to provide the final shape.

Interlocking and Non-interlocking Layouts

Double-row blank layouts can be either interlocking or non-interlocking. With non-interlocking layouts, the rows do *not* overlap in the width direction, that is, there is a line along the coil pitch direction such that one row is entirely above the line and the other row is entirely below the line. The image below shows a rotated, non-Interlocking layout; the top row is entirely above the green line, and the bottom row is entirely below the green line:



With interlocking layouts, the rows can overlap in the coil width direction. The image below shows a rotated, interlocking layout; there is no line in the pitch direction such that the top row is entirely above the line and the bottom row is entirely below the line:



Sheet Material Stock Options

The Sheet Material Stock process provides the following setup options:

- Part Spacing (trim around the part) for True-Part Shape Nesting
- Part Spacing (trim around the part) for Rectangular Nesting
- Step Angle for True-Part Shape Nesting
- Sheet Length Trim Strip—Margin along Material Length
- Sheet Width Trim Strip—Margin along Material Width
- Sheet Width Trim Strip—Margin along Material Width

Part Orientation

Specifies whether the part's tightest bend (that is, the bend with the smallest radius) is parallel to or perpendicular with the sheet grain (see [Grain Direction](#)). Select one of the following options:

- **Not Specified.** This is the default.
- **Position Bend with Smallest Radius Parallel to Grain.** Bends are sometimes oriented parallel with the grain, for example, in order to minimize cracking.
- **Position Bend with Smallest Radius Perpendicular to Grain.** Bends are sometimes oriented perpendicular to the grain, for example, to maximize strength.

This option affects part nesting.

Part Spacing (trim around the part) for True-Part Shape Nesting

By default, the width of the trim around each blank is specified by one of the following:

- For Laser Cut routings: default trim size is the product of the blank thickness and the cost model variable **laserKerfMultiplier** (0.5mm in starting point VPEs).

Default Trim Width = Blank Thickness * laserKerfMultiplier

Default trim width is bounded above by the cost model variable **kerfWidthMaxLaser** (20mm in starting point VPEs).

A routing is considered a Laser Cut routing if and only if it has a node with the node attribute **isLaserCutRouting**.

- Four Router Cut routings: default trim size is specified by the cost model variable **routerToolDiameter** (3.175mm in starting point VPEs). A routing is considered a Router Cut routing if and only if it has a node with the node attribute **isRouterCutRouting**.

If the current routing has no node with either attribute **isLaserCutRouting** or **isRouterCutRouting**, the default trim width is specified by the cost model variable **defaultSheetStockPartSpacing** (20mm in starting point VPEs).

With this setup option, you can override the default.

Note that the trim surrounds the addendum, if any, that has been added to the blank (see [Addendum Added to Blank Size](#)).

Part Spacing (trim around the part) for Rectangular Nesting

By default, the width of the trim around each blank is specified by one of the following:

- For Laser Cut routings: default trim size is the product of the blank thickness and the cost model variable **laserKerfMultiplier** (0.5mm in starting point VPEs).

Default Trim Width = Blank Thickness * laserKerfMultiplier

Default trim width is bounded above by the cost model variable **kerfWidthMaxLaser** (20mm in starting point VPEs).

A routing is considered a Laser Cut routing if and only if it has a node with the node attribute **isLaserCutRouting**.

- Four Router Cut routings: default trim size is specified by the cost model variable **routerToolDiameter** (3.175mm in starting point VPEs). A routing is considered a Router Cut routing if and only if it has a node with the node attribute **isRouterCutRouting**.

If the current routing has no node with either attribute **isLaserCutRouting** or **isRouterCutRouting**, the default trim width is specified by the cost model variable **defaultSheetStockPartSpacing** (20mm in starting point VPEs).

With this setup option, you can override the default.

- Note that the trim surrounds the addendum, if any, that has been added to the blank (see [Addendum Added to Blank Size](#)).

Grain Direction

Specifies how the grain is oriented on the sheet. Grain can run parallel to the sheet's width or length. These options are provided:

- **Parallel to Sheet Length**
- **Parallel to Sheet Width**

See also [Part Orientation](#).

Step Angle for True-Part Shape Nesting

With true-part-shape nesting (see [Material Utilization and Part Nesting for Hydroforming](#)), the cost engine uses an internal algorithm that considers multiple

candidate nesting arrangements using a variety of part orientations. By default, the various orientations differ by an angle specified by the cost model variable **defaultUtilizationStepAngle** (90° in starting point VPEs).

With this setup option, users can specify a step angle for the cost engine to use in order to generate candidate orientations—smaller nesting angles result in the consideration of a greater number of candidate nesting arrangements (which increases costing time, but may result in more efficient nesting).

Sheet Length Trim Strip—Margin along Material Length

By default, the size of the margin of material along the stock length is determined by properties of the available machines. The default margin width is the largest value that appears in the **Sheet Length Trim Strip** field for any machine. If no machine has a value for this field, the default margin width is the value of the cost model variable **standardLaserCutLeadInAmount** (10mm in starting point VPEs).

You can override the default with this setup option.

Sheet Width Trim Strip—Margin along Material Width

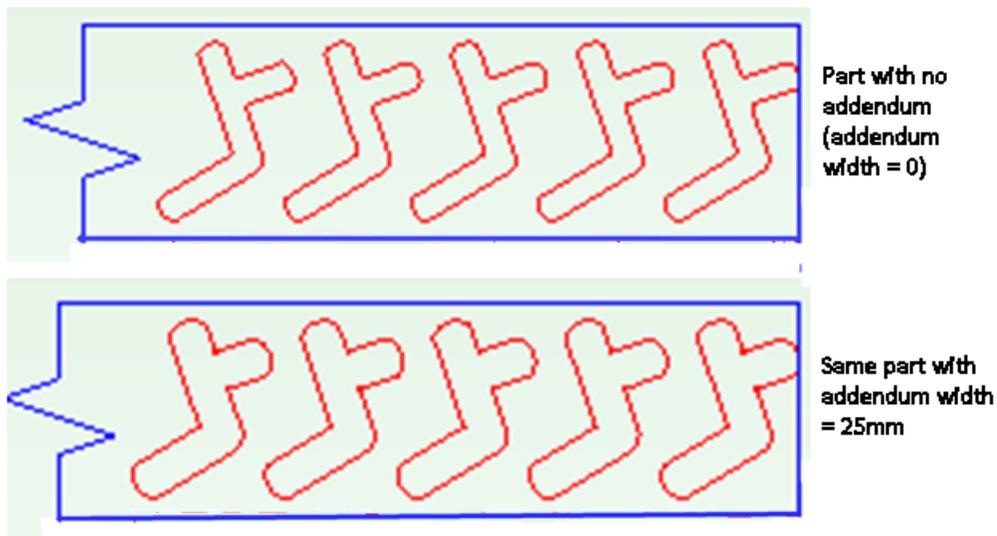
By default, the size of the margin of material along the stock width is determined by properties of the available machines. The default margin width is the largest value that appears in the **Sheet Width Trim Strip** field for any machine. If no machine has a value for this field, the default margin width is the value of the cost model variable **standardLaserCutLeadInAmount** (10mm in starting point VPEs).

You can override the default with this setup option.

Addendum Added to Blank Size

This is the width of an offset to be added all around the perimeter of the flattened part. You can enter a non-zero value in order to do one of the following:

- Add additional material for the purpose of holding the blank during the forming process, which is subsequently trimmed away.
- Compensate for cases in which aPriori underestimates flattened blank size, for example, for highly deformed parts.



Select one of the following options:

- Let aPriori Decide: this is the default, computed based on form depth and edge tolerance, using the lookup table **blankAddendumWidth**. See below.
- No Addendum: addendum size is set to 0.
- User Override: enter a value greater than or equal to 0.

If you choose Let aPriori Decide, aPriori adds addendum in all the following cases:

- Deep-draw part: the current routing is a deep draw routing (the CSL code checks for the existence of a node in the current routing with a **deepDrawFormed** attribute).
- Formed Fluid-cell part: the current routing is a fluid cell routing and the part has at least one significant form whose **Sub Type** is **EMBOSS**. An emboss form is considered significant if it takes up a sufficient fraction of the main surface (that is, if the product of the emboss's **SER Length** and **SER Width** is greater than the product of the main surface's **Convex Hull Area** and the cost model variable **mainSurfAreaMultiplier**—0.75 in starting point VPEs).
- Tight-tolerance edge: at least one blank edge has tolerance less than the cost model variable **looseEdgeToleranceThreshold** (2mm in starting point VPEs).

The width of the addendum is looked up by aggregate form depth (*excluding* forms of type **CURVED_BEND**) in the lookup table **blankAddendumWidth**. For folded parts (those with no significant emboss) that have tight tolerance, aPriori chooses the smallest addendum listed in **blankAddendumWidth**.

aP blankAddendumWidth	
Addendum Width (mm)	Total Form Depth (mm)
6.00	25.00
12.00	50.00
18.00	75.00
24.00	100.00
30.00	125.00
36.00	150.00
42.00	175.00
48.00	200.00
54.00	225.00
60.00	250.00
66.00	275.00
72.00	300.00
80.00	325.00

Aggregate form depth is the sum of the depths of all forms whose **Sub Type** is *not* **CURVED_BEND**. Each form's depth is the value of the property **Depth Up** or **Depth Down**, whichever is nonzero.

Note that when an addendum is present (whether calculated or user-specified), aPriori adds a secondary Machining operation, Profile Trimming on the 5-Axis Mill, which trims the addendum off. If no addendum is present, Blanking is assumed to provide the final shape.

Hydroform Options

Hydroform provides the following options:

- Tooling Material
- Coating of Tooling

Tooling Material

Default tool material is specified by the tool shop variable **Default Tool Material**. With this setup option, users can override the default on a per part basis, and choose from among the materials defined in the tool shop.

Coating of Tooling

Default tool coating is **None**. With this setup option, users can override the default on a per part basis, and choose from among the materials defined in the lookup table **tblToolCoating**.

Offline Blank Options

Offline Blank provides the following options:

- [Post Height Multiplier](#)
- [Part Height Allowance](#)
- [Minimum Part Height Plus Allowance](#)

Post Height Multiplier

Specifies the distance, as a multiple of post height, that must be allowed between die shoes in order to calculate the die height (which affects tooling costs).

Die height, which affects tooling cost, is the sum of the following:

- Product of post height (see [Part Height Allowance](#)) and Post Height Multiplier
- Die allowance gap (specified by the cost model variable **dieAllowanceGap**—25.4mm in starting point VPEs)
- Lower die shoe height (selected from standard shoe sizes based on blank and addendum size, as well as on whether the part has a drawn primary form, in addition to)
- Upper die shoe height (selected from standard shoe sizes based on blank and addendum size, as well as on whether the part has a drawn primary form)

By default, this multiple is specified by the cost model variable **postHeightMultiplier** (2 in starting point VPEs). You can override the default with this option.

Part Height Allowance

This setup option specifies the difference between the part height and the height of the post component of the die. The default value of Part Height Allowance is specified by the cost model variable **partHeightAllowance** (12.7mm in starting point VPEs). You can override the default with this option.

Note that the post height is constrained by the value of [Minimum Part Height Plus Allowance](#). That is, the post height is either the sum of the part height and the value of Part Height Allowance, or the value specified by [Minimum Part Height Plus Allowance](#), whichever is greater.

See also [Post Height Multiplier](#).

Minimum Part Height Plus Allowance

This setup option constrains the height of the die post (which affects die height and tooling cost—see [Tooling for Hydroforming](#)). The post height is either the sum of part height and [Part Height Allowance](#), or the value specified by this option, whichever is greater.

The default value for this option is specified by the cost model variable **minimumPartHeightPlusAllowance** (50.8mm in starting point VPEs). You can override the default by entering a value for this option.

14 Sheet Metal— Transfer Die

The Sheet Metal—Transfer Die process group lets you estimate manufacturing times and costs for the transfer die fabrication processes and subsequent machining operations. The cost model includes estimates of hard tooling costs. This chapter describes the costing details and inputs that are available for the Sheet Metal—Transfer Die process group. For detailed information on other sheet metal processes, see the chapters [Sheet Metal—Hard Tooled](#) and [Sheet Metal—Soft Tooled](#), [Sheet Metal—Hydroforming](#), and [Sheet Metal—Stretch Forming](#).

This chapter includes the following topics:

- [Cost Model Overview for Transfer Die](#)
 - [Transfer Die Quick Start](#)
 - [GCD Extraction for Transfer Die](#)
 - [Tooling for Transfer Die](#)
 - [User Inputs for Transfer Die](#)
-

Cost Model Overview for Transfer Die

This overview contains the following sections:

- Transfer Die General Process
- Part Geometry for Transfer Die
- Materials and Stock Forms for Transfer Die
- Material Utilization and Part Nesting for Transfer Die
- Machines for Transfer Die
- Tooling Overview for Transfer Die

Transfer Die General Process

Transfer die supports features and practices commonly used in automotive sheet metal manufacturing. These include deep draw forming operations, side-action forming (cam-actuated), support for multiple trim stages, and support for performing holemaking (piercing, countersinking, extruding, coning, shaving, and tapping) prior to or subsequent to bending and forming operations. The cost model assumes blanking is done offline, on a separate machine, and blanks are fed into the transfer press. The model supports options for specifying strip layouts during offline blanking. The model also supports options for specifying blank orientation and concurrent part stamping as it pertains to the transfer press.

The transfer die process consists of a series of stations that progressively form the finished part. Transfer die is similar to progressive die, but transfer die is often used to make parts that are larger or drawn deeper than those typical of progressive die. Stations are physically fastened to a die shoe, which is the tooling platform that is loaded into a stamping press. Transfer die tooling includes a die set for every station, and is typically more expensive than for progressive die. (For more about how transfer die compares to other hard-tooled sheet metal routings, see [Hard Tooled Sheet Metal General Process](#).)

Typical parts that are well-suited to the cost model have large primary forms that are made with a small number of forming operations, with outlying flanges that are wiped separately or created as a result of being held by the binder.

The model makes the following additional assumptions:

- Parts are inherently balanced in the sense that they do not require a significant non-uniform addendum on one side of the part to balance the material available for the drawing/forming operations.
- Parts are produced using either a 1-out layout or a *non-attached* 2-out layout.

The model also assumes that each die set has a single die station.

The transfer die cost model supports a routing that involves the following processes:

- **Offline Blanking**
- **Transfer Die**

Possible Transfer Die operations include the following:

- Drawing
- Crash Forming
- Pad and Wipe
- Embossing
- Stamping
- Bending
- Down OverBending
- Scoring
- Setting
- Trimming
- Piercing
- Coining
- Tapping
- Shaving
- Notching
- Restriking
- Separate
- Cam Action Bending
- Cam Action Coining
- Cam Action CounterSinking
- Cam Action Extruding
- Cam Action Lancing
- Cam Action Piercing-Trimming
- Cam Action Shaving
- Cam Action Tapping
- Cam Action Developed Trimming
- Direct Developed Trimming

Active part tipping is not currently supported; the model assumes that any required tipping occurs automatically as a function of how the part sits on a given station.

Although the starting point VPE assumes blanking is done offline, it can be configured for inline blanking—please contact aPriori Support or your aPriori Account Manager. A future release will add out-of-the-box support for inline blanking.

Note that the cost model relies on a *node occurrence generator* Java plugin (specified by the node attribute **generatorName**) to group operations by die station. See *Working with Zero-or-More Nodes* in the Cost Model Workbench Guide for more information.

This cost model is available via a separately licensed module.

If you have licensed the appropriate modules, your routing can include optional machining processes.

Part Geometry for Transfer Die

A small selection of example parts is shown below.



Geometry extraction for the Transfer Die process group identifies some sheet-metal-specific and transfer-die-specific features:

- Blank GCD
- Ram Direction for Transfer Die
- Main Surface for Transfer Die
- Form GCD
- Cam Bundling for Transfer Die
- LIES_NEAR Relation
- LIIES_OUTSIDE Relation

In addition to solid CAD models, the Transfer Die process group supports *surface* CAD models, which represent surfaces only, rather than solid geometry. See [Surface-only CAD Models for Transfer Die](#) for more information.

See [GCD Extraction for Transfer Die](#) for more information.

Materials and Stock Forms for Transfer Die

Transfer die assumes the use of virtual coil stock. Stock width is based on the results of the strip nesting calculations—see [Material Utilization and Part Nesting for Transfer Die](#). Stock thickness is based on part thickness.

aPiori assumes the required virtual stock can be obtained at the price per unit weight specified by the material property **Default Cost per KG**. In starting point VPEs, stock width cannot exceed 1828.8mm, by default. You can override the default allowable width range with the PSOs **Minimum Strip Width** and **Maximum Strip Width**. VPE administrators can customize the default range with the cost model variables **minimumStripWidth** and **maximumStripWidth**. A part fails to cost if it requires a stock width that falls outside the allowable range.

Note to VPE Administrators: Actual stocks are *not* supported. Do not add actual stock to a Sheet Metal—Transfer Die VPE.

Materials include the following:

- Aluminum: 3003, 5052, 6061
- Copper: 110
- Galvanized Steel: HR-1010, HR-1012, HR-1020

- Stainless Steel: 304, 316, 316L
- Steel: CR-1010, CR-1012, CR-1020, HR-1010, HR-1012, HR-1020

Material composition details include the following:

- Unit Cost (USD / kg)
- Density (kg / m³)
- Shear Strength (MPa)
- Ultimate Tensile Strength (MPa)

Material details include equivalent DIN and EN name standards for use with regional VPEs.

Note: If you change the selected material for a part, the part's CAD file must be accessible to aPriori so that it can recalculate the flattened part outline.

Material Utilization and Part Nesting for Transfer Die

The material cost of a sheet metal part is based on the rough mass required to make the part. The utilization is equal to the finish mass of the part divided by the rough mass—rough mass includes any material scrap.

aPriori provides multiple methods for computing sheet metal material utilization. A true-part shape nesting (TPSN) algorithm is used by default. In order to maximize material utilization and minimize waste, this algorithm finds the tightest nesting for parts using the blank's actual perimeter. Note that the TPSN algorithm used by transfer die (and progressive die—see [Sheet Metal—Hard Tooled](#)) differs from the TPSN algorithm used by soft-tooled processes (see [Sheet Metal—Soft Tooled](#)) in the following respect:

- Transfer die: uses an optimized strip-nesting algorithm in which parts are nested in rows, and all parts in a row have consistent orientations.
- Soft-tooled: allows neighboring parts to have different orientations, and doesn't constrain parts to be organized into rows.

The **Material Selection** dialog (in the Manufacturing Process pane) provides you with four options for calculating utilization:

- **Rectangular Nesting:** assumes the part is rectangularly nested on a sheet, with either a lengthwise or widthwise orientation (whichever is more efficient).
- **True-Part Nesting** (strip nesting): uses the component's actual perimeter to determine nesting, and tests various rotations of the component. See also [Blank GCD](#) and [Blank XY Orientation within Part Strip](#) for more information on transfer die strip nesting.
- **Machine Default:** uses the current machine's associated average material utilization (the machine property **Avg Utilization**); use this to estimate material costs for dynamic nesting.
- **Override:** uses a fixed utilization value entered by user; use this when you know the exact utilization based on a supplier's nesting pattern.

VPE administrators can customize the default utilization method with the cost model variable `defaultUtilizationMethod`.

The current nesting pattern on the currently selected stock is viewable in the Viewer using the **Analysis** menu. See [Blank GCD](#). The stock can be changed via the **Material Selection** dialog.

Setup options for controlling trim strips, margins, and addenda are available—see [Setup Options for Transfer Die](#).

Machines for Transfer Die

The following tables list important machine property value ranges. Ranges are listed below for those processes that support a choice of machines:

Offline Blanking

Property	Low End	High End
Press Force (kN)	658.00	9,964.00
Press Table Length (mm)	703.00	5,181.60
Press Table Width (mm)	609.60	2,590.80
Shut Height (mm)	330.00	1,372.00

Transfer Press

Property	Low End	High End
Press Force (kN)	383.61	40,000.00
Press Table Length (mm)	701.04	20,000.00
Press Table Width (mm)	398.78	5000.00
Shut Height (mm)	210.06	1500.00

aPiori selects the machine with the lowest adequate press force that can accommodate the part's dimensions. Adequate press force is the sum of the required shearing, forming, drawing, and holding forces, and is based on GCD dimensions, blank thickness, and material shear strength. Required press force is displayed in the Investment tab.

Tooling Overview for Transfer Die

A part's tooling costs for transfer die depend, among other things, on the number of stations required to produce the part. The required number of stations depends roughly on the following factors:

- GCD proximity: GCDs that lie too close together must be made at different stations.
- GCD direction: GCDs that share the same direction that are not too close can often be made at the same station.
- Operation precedence: Operations that cannot be performed at the same time or that need to follow an order of precedence cannot be made at the same stage or station. For example, forming the primary form must occur with or before hole piercing, and a bend must be performed before any bend that lies between it and the main surface (see [Main Surface for Transfer Die](#) and [LIIES_OUTSIDE Relation](#)).

Based on the number-of-stations analysis, aPiori determines which features will be manufactured at each station. Once all features have been associated with a station, aPiori calculates the tool base and tool shop cost for the entire tool, based on the part size and feature set (including the holes, bends, and forms).

For Transfer Die and Offline Blanking, the tooling model estimates the number of parts that can be produced with a given tool before it wears to the point that it needs to be replaced. Based on that estimate, the cost model determines the number of tools

required to manufacture the production volume specified in the Production Scenario tab of the Cost Guide, and accounts for that number of tools in total hard tooling cost.

Tool-life estimation is based on part material, and adjusted for tool material and tool coating type. For a given costing, either the formula Dependencies or Investment tab displays the number of tools assumed by tooling cost calculations.

Bill of material costs include the following:

- Die Blocks
- Die Shoes
- Punch Holders
- Top/Bottom Parallels
- Punch Pads
- Strippers
- Spring
- Hardware
- Guide Pins
- Punches
- Inserts

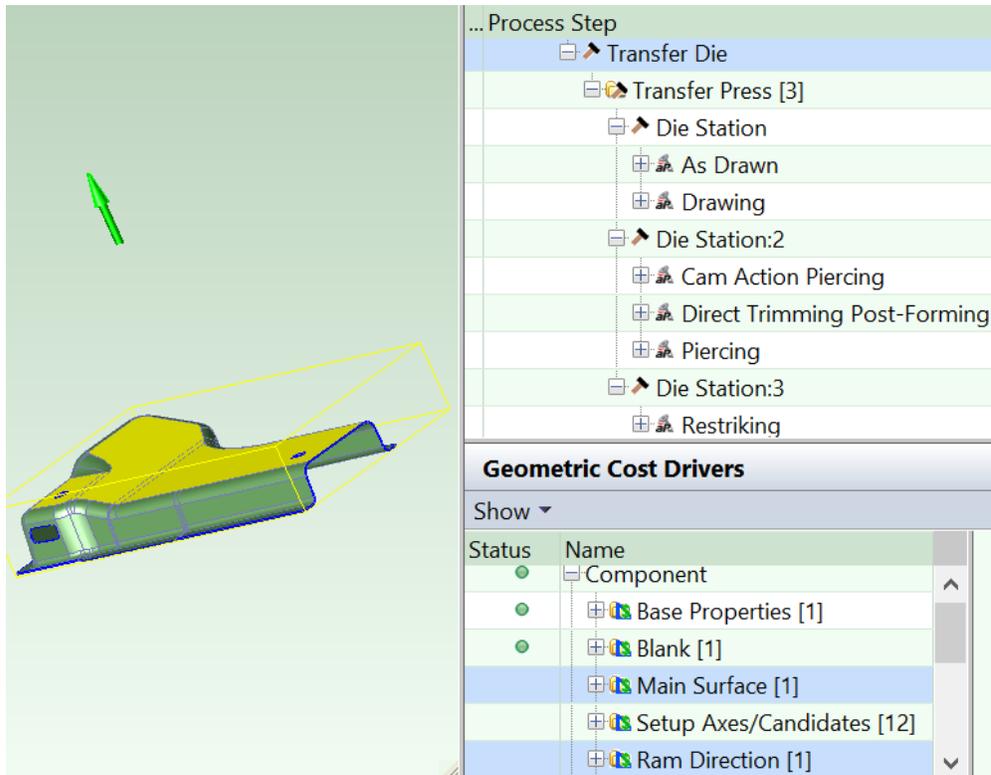
Labor costs include the following:

- Assembly
- CNC Machining
- CNC Programming
- Debug
- Design
- Drilling
- Grinding
- Lathe
- Milling
- Rework
- Sawing
- Wire EDM

See [Tooling for Transfer Die](#) for more information.

Transfer Die Quick Start

Below is a Transfer Die costing of a sample part. The part is shown in the Viewer, together with a green arrow representing the ram direction (the direction from which the ram approaches the part—see [Ram Direction for Transfer Die](#)). You can display the ram direction by selecting the Ram Direction GCD in the Geometric Cost Drivers pane. The main surface is also highlighted in yellow (see [Main Surface for Transfer Die](#)). You can highlight the main surface by selecting the Main Surface GCD in the Geometric Cost Drivers pane.



This part is routed to Offline Blanking and then to several Transfer Die stations:

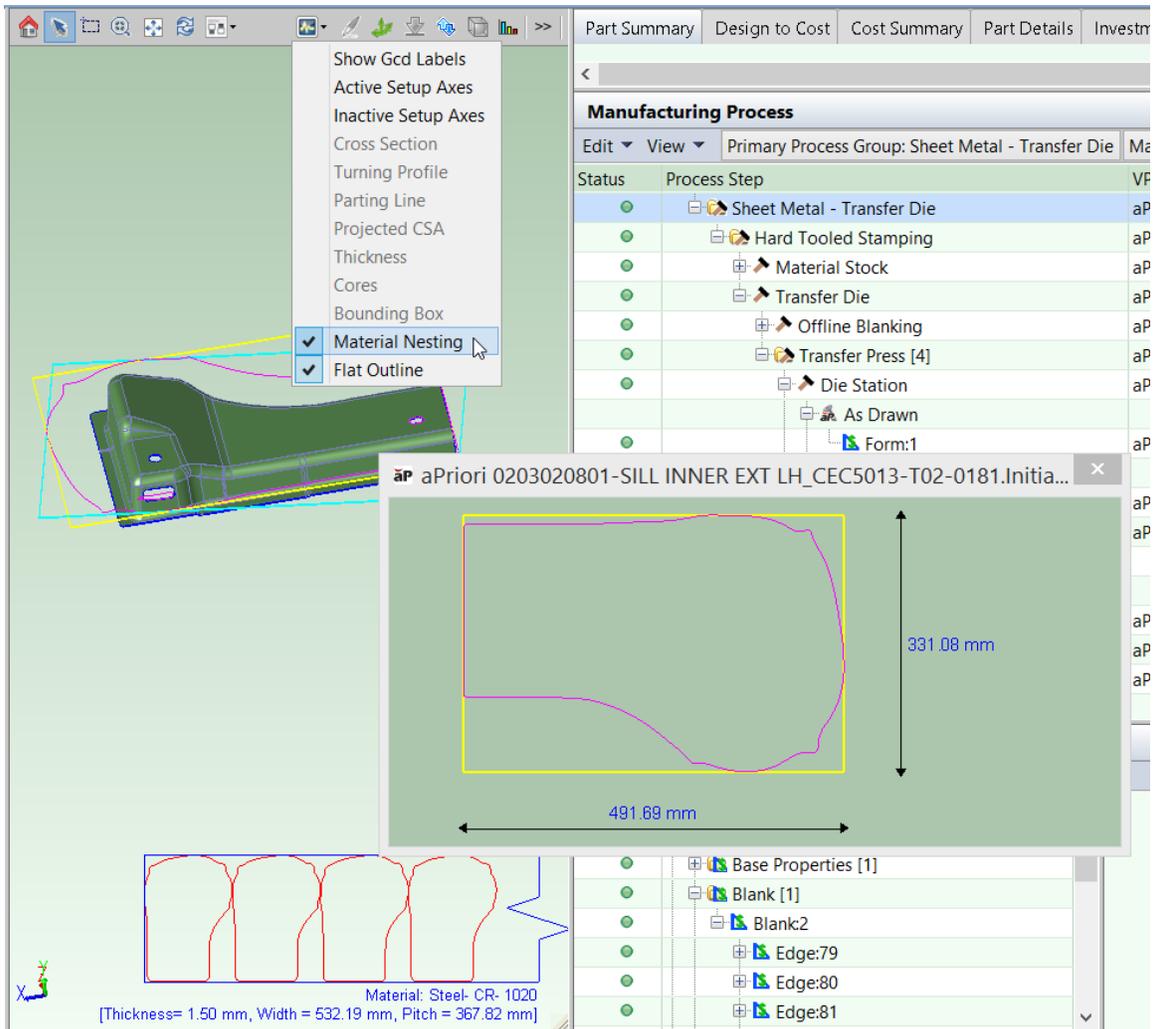
- Offline Blanking
- Die Station 1: Drawing
- Die Station 2: Edge Trimming, Direct Piercing, and Cam Piercing
- Die Station 3: Restriking

Offline Blanking

Transfer Die routings start with Offline Blanking on a machine that is separate from the transfer press. (The current release can be configured for inline blanking—please contact aPriori Support or your aPriori Account Manager. A future release will add out-of-the-box support for inline blanking.)

By default, aPriori uses finite element analysis to determine the shape of the flattened part which blanking creates—see [Flattening for Transfer Die](#). In addition, blanking attempts to optimize material utilization by using a strip nesting algorithm. The cost model assumes the use of virtual sheet stock whose width is based on the results of the strip nesting calculations and whose thickness is based on part thickness—see [Materials and Stock Forms for Transfer Die](#), [Material Utilization and Part Nesting for Transfer Die](#), and [Blank GCD](#). Several setup options allow you to configure the nesting calculation or control the orientation of the flattened blank on the stock—see [User Inputs for Transfer Die](#).

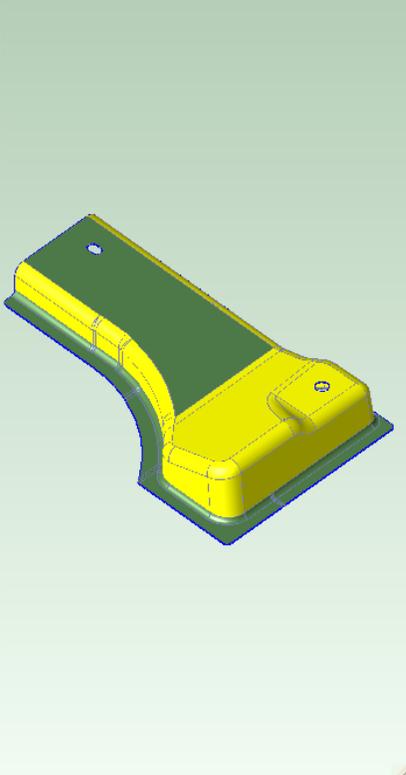
You can display the flat pattern and its associated SER (smallest enclosing rectangle) by selecting **Flat Outline** from the Analysis menu in the Viewer toolbar. You can display the orientation of the blank on the stock by selecting **Material Nesting** from the Analysis menu in the Viewer toolbar. The nesting orientation is displayed at the bottom of the Viewer.



Note that, since this part is not balanced in the sense described in [Transfer Die General Process](#), if the part were produced as a 1-out part, the material required would be somewhat greater than that predicted by aPriori.

Die Station 1: Drawing

For many parts, the first station draws the part's primary form (the part's largest form of subtype EMBOSS that is adjacent to the main surface--see [Primary Forming for Transfer Die](#)).



Manufacturing Process

Edit Primary Process Group: Sheet Metal - Transfer Die Material: Steel

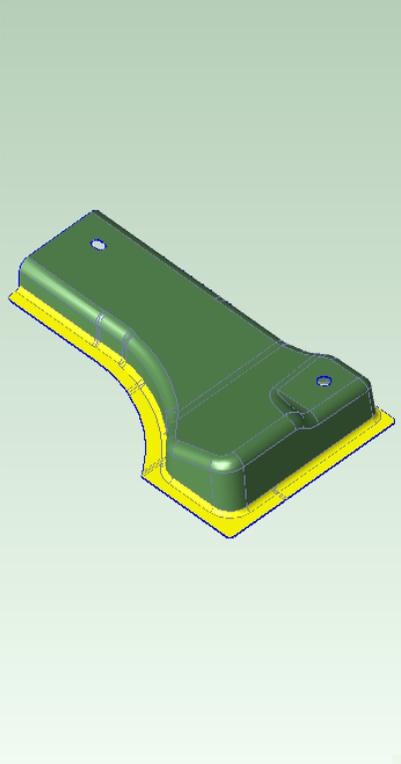
... Process Step	VPE
Transfer Die	aPriori USA
Transfer Press [3]	aPriori USA
Die Station	aPriori USA
As Drawn	
Form:1	aPriori USA
Drawing	
Form:2	aPriori USA
Die Station:2	aPriori USA
Cam Action Piercing	
Direct Trimming Post-Formi	

Geometric Cost Drivers

Show ▾

Status	Name	... Name	Property Result
●	Component	Name	Form:2
●	Bending/Forming	Area (mm^2)	72,122.19
●	Forms [2]	SER Length (mm)	471.76
●	Form:1	SER Width (mm)	300.29
●	Form:2	User Defined	false
●	Holes	Sub Type	EMBOSS
●	Surfaces	Depth Down (mm)	69.50

A flange, such as the one shown in yellow below, is recognized by geometry extraction as a form that is separate from but related to the primary form. The model assumes that this flange is formed by the same drawing operation that creates the primary form. Since a single occurrence of the Drawing operation creates both the primary form and the flange, the flange is assigned to the operation As Drawn, which carries no additional cost.



Manufacturing Process	
Edit	Primary Process Group: Sheet Metal - Transfer Die | Material: Steel
... Process Step	VPE
Transfer Die	aPriori USA
Transfer Press [3]	aPriori USA
Die Station	aPriori USA
As Drawn	
Form:1	aPriori USA
Drawing	
Form:2	aPriori USA
Die Station:2	aPriori USA
Cam Action Piercing	
Direct Trimming Post-Formi	

Geometric Cost Drivers			
Show			
Status	Name	... Name	Property Result
	Form:1	Name	Form:1
	PlanarF	Area (mm^2)	26,338.71
	PlanarF	SER Length (mm)	491.40
	PlanarF	SER Width (mm)	331.08
	PlanarF	User Defined	false
	PlanarF	Sub Type	CURVED_BEND
	PlanarF	Depth Down (mm)	0.00

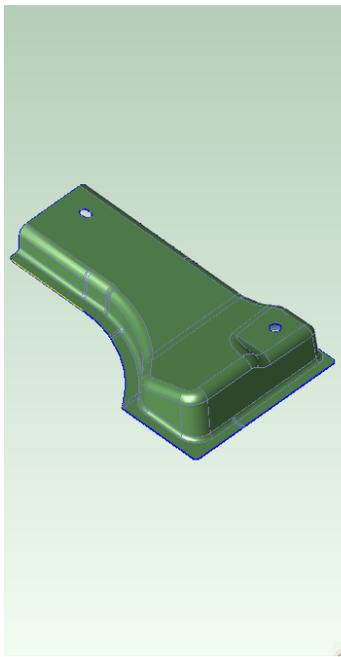
Die Station 2: Edge Trimming, Direct Piercing, and Cam Piercing

The cost model assumes that after forming has been performed, direct or cam trimming is required for blank edges that have tight tolerance—see [Edge Trimming](#). In addition, holes that are accessible from the ram direction are direct pierced—see [Direct Piercing](#). Holes not accessible from the ram direction must be cam pierced—see [Cam Piercing](#).

Edge Trimming

Post-form trimming is triggered for edge segments whose positional tolerance is tighter than the threshold specified by the cost model variable **edgeTrimmingPositionToleranceThreshold** (2mm in starting point VPEs). If you haven't specified the positional tolerance of an edge, the cost model assumes the tolerance specified by the cost model variable **defaultPositionToleranceEdgeSegment** (1.5mm in starting point VPEs). Note that all tolerances are bilateral; positional tolerance specifies the diameter of the tolerance zone.

In this example, the tolerance isn't specified, and so is assumed to be 1.5mm. This is less than the 2mm threshold, so trimming is performed.



Manufacturing Process			
Edit	Primary Process Group: Sheet Metal - Transfer Die	Material: Steel, Cold Worked, AISI 1020	
Process Step	VPE	Machine	
Transfer Die	aPriori USA	Transfer Die Pres	
Transfer Press [3]	aPriori USA		
Die Station	aPriori USA		
Die Station:2	aPriori USA		
Cam Action Piercing			
Direct Trimming Post-Formi			
EdgeSegment:1	aPriori USA		
EdgeSegment:2	aPriori USA		
EdgeSegment:3	aPriori USA		
EdgeSegment:4	aPriori USA		

Geometric Cost Drivers			
Status	Name	Name	Property Result
	Blank:1	Name	EdgeSegment:2
	Edge:50	Tangent Direction	(-1.00, 0.00, 0.00)
	Edge:51	Direction Into Side	(0.00, -1.00, 0.00)
	EdgeSegment:2	Length (mm)	129.82
	Edge:52	Tolerance (coordinate) (mm)	<unspecified>
	Edge:53	True Position (mm)	<unspecified>
	Edge:54	Requested	<auto-select>

An edge segment can be direct trimmed if both the following hold:

- It can be accessed from a direction that is sufficiently close to the ram direction.
- It is not too close to vertical (aligned with the ram direction) or it is short enough and any adjacent edge segments are also direct trimmed.

Other edge segments must be cam trimmed. See [Cam Bundling for Transfer Die](#).

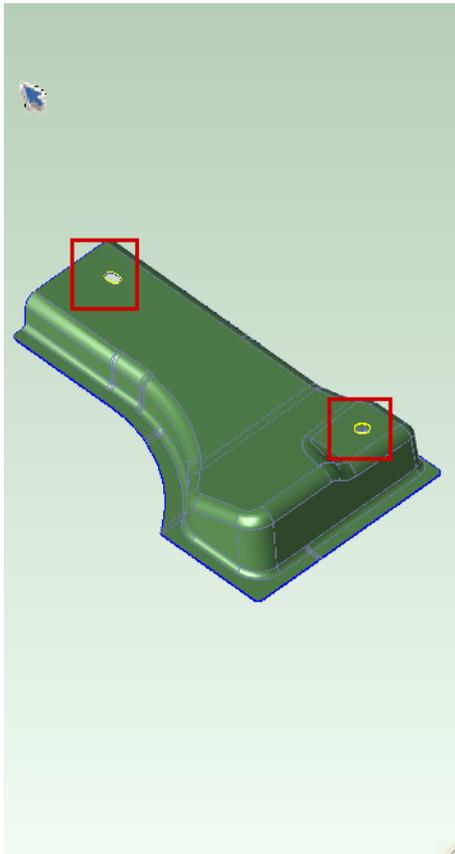
You can customize what counts as sufficiently close to the ram direction with the cost model variable **maxRamDirectionTangentAngle** (30 degrees in starting point VPEs).

You can customize what counts as too close to vertical with the cost model variable **minOpenAngleEdgeTrimming** (3 degrees in starting point VPEs). And you can customize what counts as short enough with the cost model variable **verticalTrimLengthThreshold** (25.4mm in starting point VPEs.)

All edge segments in this example can be direct trimmed.

Direct Piercing

In this example, the holes on the top of the part are accessible from a direction that is sufficiently close to the ram direction, and so are direct pierced. The cost model variable **maxRamDirectionTangentAngle** (30 degrees in starting point VPEs) controls the threshold for both edge trimming and hole piercing.



Manufacturing Process

Edit Primary Process Group: Sheet Metal - 1

... Process Step

- Transfer Die
 - Transfer Press [3]
 - Die Station
 - Die Station:2
 - Cam Action Piercing
 - Direct Trimming Post-Fo
 - Piercing
 - ComplexHole:2
 - SimpleHole:1
 - Die Station:3

Geometric Cost Drivers

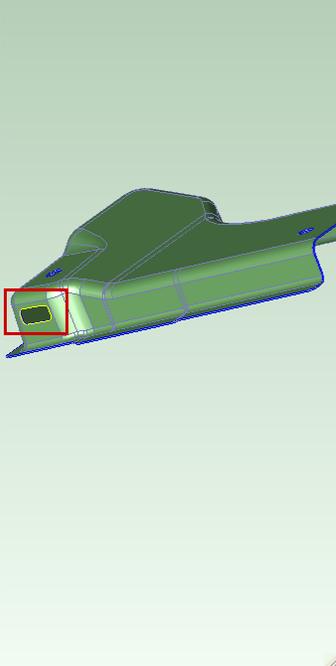
Show ▾

Status	Name
	GCD Relations
●	Form:2
●	Holes
●	Simple Holes [1]
●	SimpleHole:1
●	Complex Holes [1]
●	ComplexHole:2

Other holes must be cam pierced—see Cam Piercing.

Cam Piercing

The hole on the vertical side of the part is not accessible from a direction that is sufficiently close to the ram direction, so it is cam pierced. You can customize what counts as sufficiently close for these purposes with the cost model variable **maxRamDirectionTangentAngle** (30 degrees in starting point VPEs).



Manufacturing Process

Process Step	VPE	Machine
Offline Blanking	aPriori USA	Offline Blank
Transfer Die	aPriori USA	Transfer Die F
Transfer Press [3]	aPriori USA	
Die Station	aPriori USA	
Die Station:2	aPriori USA	
Cam Action Piercing		
ComplexHole:1	aPriori USA	
Direct Trimming Post-Formi		
Piercing		
Die Station:3	aPriori USA	

Geometric Cost Drivers

Show ▾

Status	Name	... Name	Property Result
●	ComplexHole:2	Name	ComplexHole:1
●	Surfaces	Area (mm^2)	600.91
●	Other	SEC Diameter (mm)	39.60
●	Edges [47]	Mec Diameter (mm)	16.00
●	Cam Bundles [1]	Perimeter (mm)	101.33
●	CamBundle:1	SER Length (mm)	39.26
●	ComplexHole:1	SER Width (mm)	16.00

The same cam can do both trimming and piercing, and can generally handle both multiple edges and multiple holes, as long as all the features are accessible from the same direction. Cams are represented by CamBundle GCDs, and the Geometric Cost Drivers pane allows you to see which features each cam handles. See [Cam Bundling for Transfer Die](#).

By default, aPriori assumes that the presence of cams does not require an IDLE station to accommodate extra space for the cam units. But you can override the default by enabling auto-inclusion of IDLE stations—see [Enable Auto-Inclusion of IDLE Stations](#).

Die Station 3: Restriking

In this example, Restriking is performed on the drawn form, because the selected material has a tensile yield strength that exceeds the value of the cost model variable `matYieldStrengthRestrikeThreshold` (344.74 N/mm² in starting point VPEs).

Manufacturing Process

Edit Primary Process Group: Sheet Met

... Process Step

- Transfer Die
 - Transfer Press [3]
 - Die Station
 - As Drawn
 - Drawing
 - Form:2
 - Die Station:2
 - Die Station:3
 - Restriking (highlighted)
 - Form:2 (highlighted)

Geometric Cost Drivers

Show ▾

Status	Name
	Ram Direction [1]
	Sides [2]
●	Bending/Forming
●	Forms [2]
●	Form:1
●	Form:2 (highlighted)
●	Holes

Material Composition

Requested: MCAD : Not_Assigned

Selected: VPE Default : Steel- CR- 1020

Edit Selection Policy ▾

Primary ID	Other				
Name	Density (kg / m ³)	Hardness	Hardnes...	Tensile Yield Strength (MPa)	Ultimate...
Steel- CR- 1010	7,850	0.00	Brinell	305.00	365.00
Steel- CR- 1012	7,850	0.00	Brinell	310.00	370.00
Steel- CR- 1020	7,850	0.00	Brinell	350.00 (highlighted)	420.00
Steel- HR- 1010	7,850	0.00	Brinell	180.00	325.00
Steel- HR- 1012	7,850	0.00	Brinell	185.00	330.00

Restriking is also sometimes performed for a number of reasons besides material strength:

- **Width-to-depth ratio:** the form's width-to-depth ratio is less than the cost model variable `widthToDepthRestrikeThreshold` (0.5 in starting point VPEs). The width-to-depth ratio is the **SER Width** divided by the sum of **Depth Up** and **Depth Down**.
- **Depth-to-thickness ratio:** the ratio of the form's depth to the blank's thickness is less than the cost model variable `depthToMatlThicknessRestrikeThreshold` (1000 in starting point VPEs). The depth-to-thickness ratio is the sum of **Depth Up** and **Depth Down** divided by the material thickness.
- **Minimum radius of curvature:** the form's smallest radius of curvature is less than 10 times the blank thickness. You can customize the blank thickness multiplier

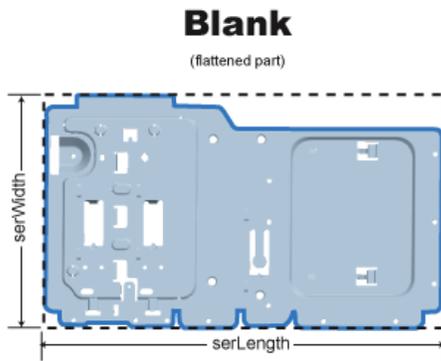
- (10 in starting point VPEs) with the cost model variable **minRadiusOfCurvatureRestrikeThresholdMultiplier**.
- *Surface tolerance*: the tolerance some surface of the form is tighter than the cost model variable **minFormSurfaceToleranceRestrikeThreshold** (0.5 in starting point VPEs).

Restriking can occur on the same die station along with multiple other operations, provided those operations are not performed on the surfaces being restruck and do not otherwise interfere with the restriking operation and tooling.

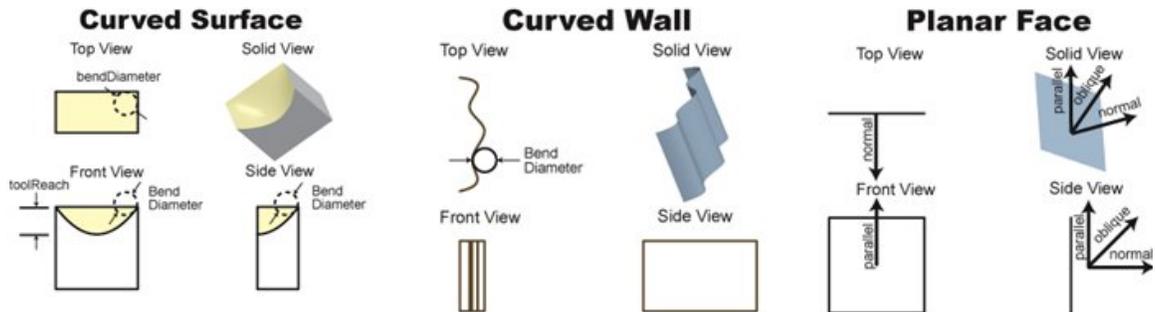
GCD Extraction for Transfer Die

aPiori extracts the geometry of a CAD model in the form of geometric cost drivers (GCDs) that include surfaces and holes, as well as bending and forming GCDs, lances, and a GCD that represents the flattened blank from which the sheet metal part is formed. As usual, there is a special GCD, **Component**, which represents the part as a whole. Below are some of the important properties of each of these GCD types. Each GCD's units are shown in metric.

- **Component:**
 - Volume (mm³)
 - Surface Area (mm²)
 - Length, Width, and Height (millimeters)
 - Number of Surfaces
 - Min Thickness, Max Thickness, and Avg Thickness (millimeters)
 - Length Direction, Width Direction, and Height Direction: each of these is a unit vector, two of whose components are 0 (the other component is 1 or -1). These vectors can be compared with the Direction vector of another GCD (such as a Setup Axis) in order to determine whether the GCD's direction is aligned with the part's length, width, or height.
- **Blank:**
 - Perimeter (millimeters)
 - SER Length and SER Width (smallest-area enclosing rectangle dimensions in millimeters)
 - SWER Length and SWER Width (smallest-width enclosing rectangle dimensions in millimeters)
 - Thickness (millimeters)
 - Straight Length (millimeters)

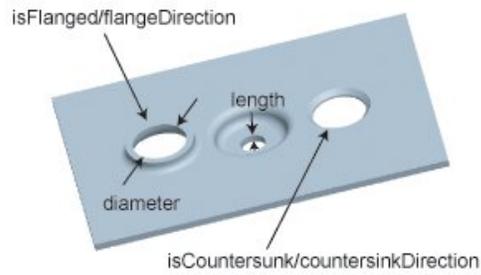


- **Surfaces (Curved Surface, Curved Wall, and Planar Face):**
 - Finished Area (mm^2)
 - Bend Diameter (millimeters)
 - Perimeter (millimeters)
 - SER Length and SER Width (smallest enclosing rectangle dimensions in millimeters)
 - Corner Diameter (millimeters)
 - Inside Diameter (millimeters)
 - Number of Surfaces
 - Fillet Min Angle and Fillet Max Angle (degrees)
 - Round Radius (millimeters)
 - Round Length (millimeters)
 - Wall Corner Diameter (millimeters)

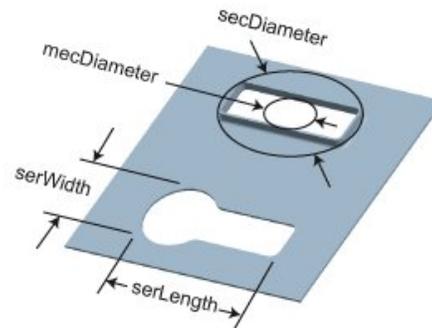


- **Holes (Simple Hole, Complex Hole):**
 - Diameter (millimeters),
 - Length and Depth (millimeters)
 - Volume (mm^3)
 - Surface Area (mm^2)
 - Hole type (THROUGH or BLIND)
 - Blind, Sleeve Pin, Threaded, Countersunk, and Flanged (TRUE or FALSE)

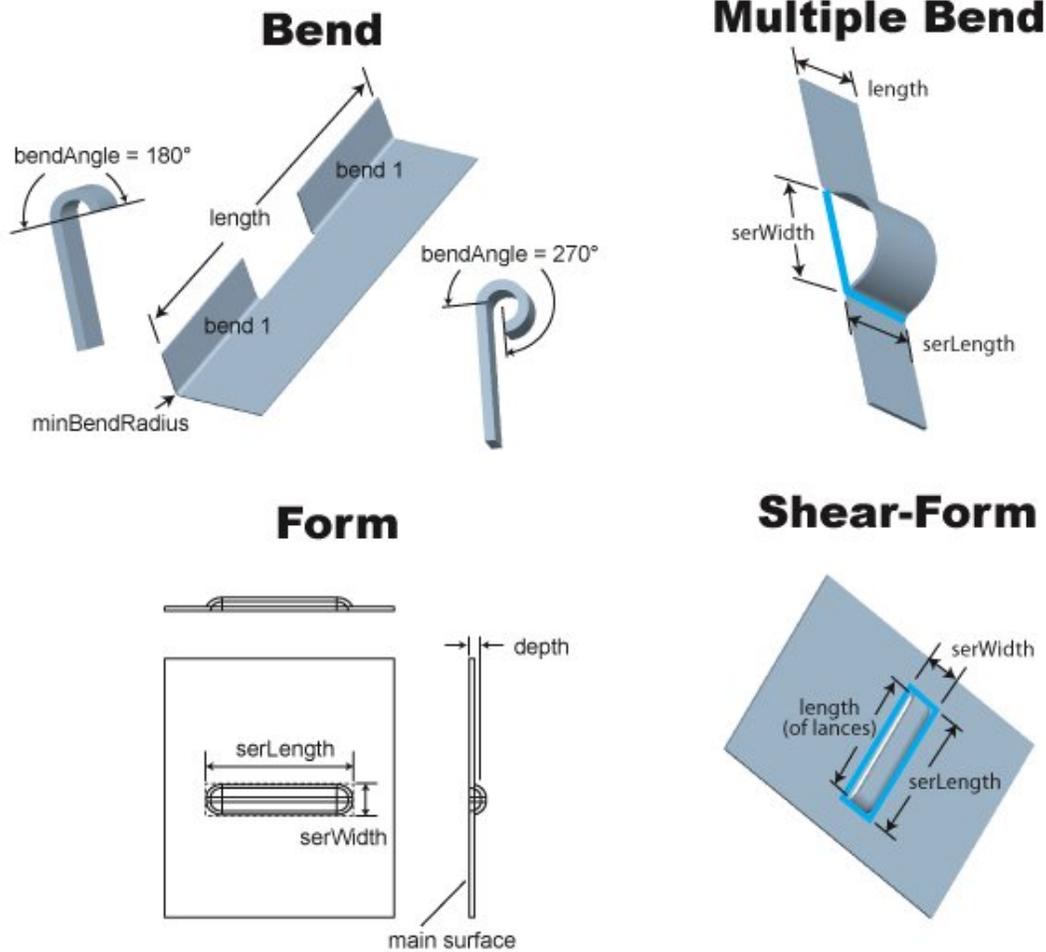
Simple Hole



Complex Hole



- **Bending/Forming (StraightBend, Multi Bend, Form, ShearForm):**
 - Bend Angle (degrees)
 - Length (millimeters)
 - Bend Flap Size (millimeters)
 - Min Bend Radius (millimeters)
 - SER Length (millimeters)
 - SER Width (millimeters)
 - Perimeter (millimeters)



- **Lance:**
 - Length (millimeters)

More information on special sheet metal GCDs and properties is contained in the following sections:

- Blank GCD
- Ram Direction for Transfer Die
- Main Surface for Transfer Die
- Form GCD
- Cam Bundling for Transfer Die
- LIES_NEAR Relation
- LIIES_OUTSIDE Relation
- Surface-only CAD Models for Sheet Metal

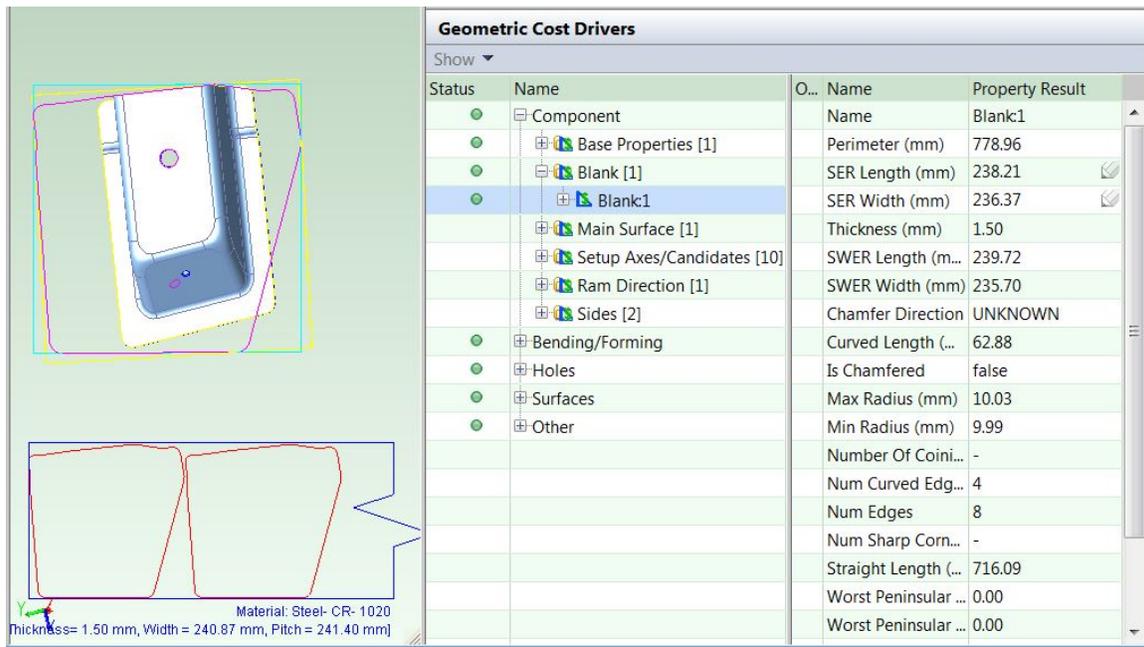
Blank GCD

The Blank GCD is specific to the Sheet Metal process groups. It represents the flattened part. Its properties (such as **Perimeter**, **Thickness**, **SER Length**, and **SER Width**) are listed in

the Geometric Cost Drivers pane, and are all *independent* of the blank's orientation on the stock coil or sheet during offline blanking.

When you select the Blank GCD in the Geometric Cost Drivers pane, the Viewer displays the following:

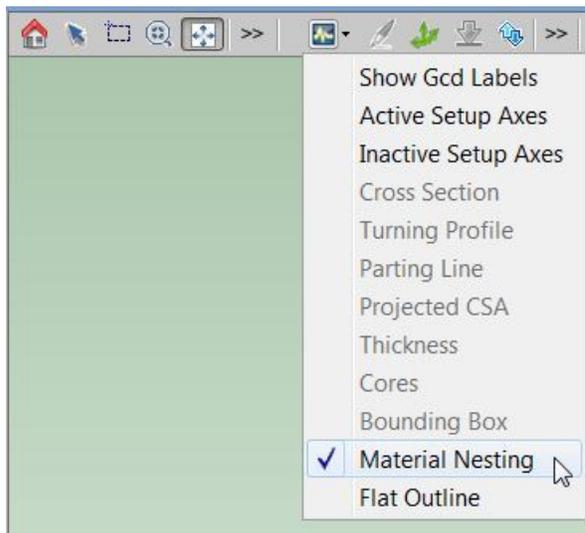
- Blank outline in pink
- Blank SER in yellow: this is the smallest-area rectangle that encloses the blank.
- Blank SWER in blue: this is the smallest-width rectangle that encloses the blank. By default, in order to minimize transfer pitch, aPriori orients the blank in the transfer press so that the width of the SWER is parallel to the transfer pitch direction (assuming the SER and SWER differ significantly in width). You can override the default with the setup option [Determine Transfer Pitch Based on:](#).

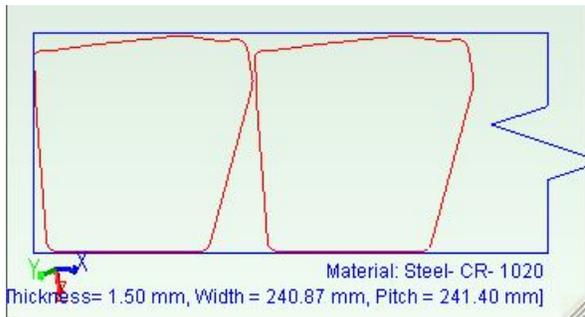


Status	Name	O...	Name	Property Result
●	Component		Name	Blank:1
●	Base Properties [1]		Perimeter (mm)	778.96
●	Blank [1]		SER Length (mm)	238.21
●	Blank:1		SER Width (mm)	236.37
●	Main Surface [1]		Thickness (mm)	1.50
●	Setup Axes/Candidates [10]		SWER Length (m...	239.72
●	Ram Direction [1]		SWER Width (mm)	235.70
●	Sides [2]		Chamfer Direction	UNKNOWN
●	Bending/Forming		Curved Length (...)	62.88
●	Holes		Is Chamfered	false
●	Surfaces		Max Radius (mm)	10.03
●	Other		Min Radius (mm)	9.99
			Number Of Coini...	-
			Num Curved Edg...	4
			Num Edges	8
			Num Sharp Corn...	-
			Straight Length (...)	716.09
			Worst Peninsular ...	0.00
			Worst Peninsular ...	0.00

Material: Steel- CR- 1020
Thickness= 1.50 mm, Width = 240.87 mm, Pitch = 241.40 mm

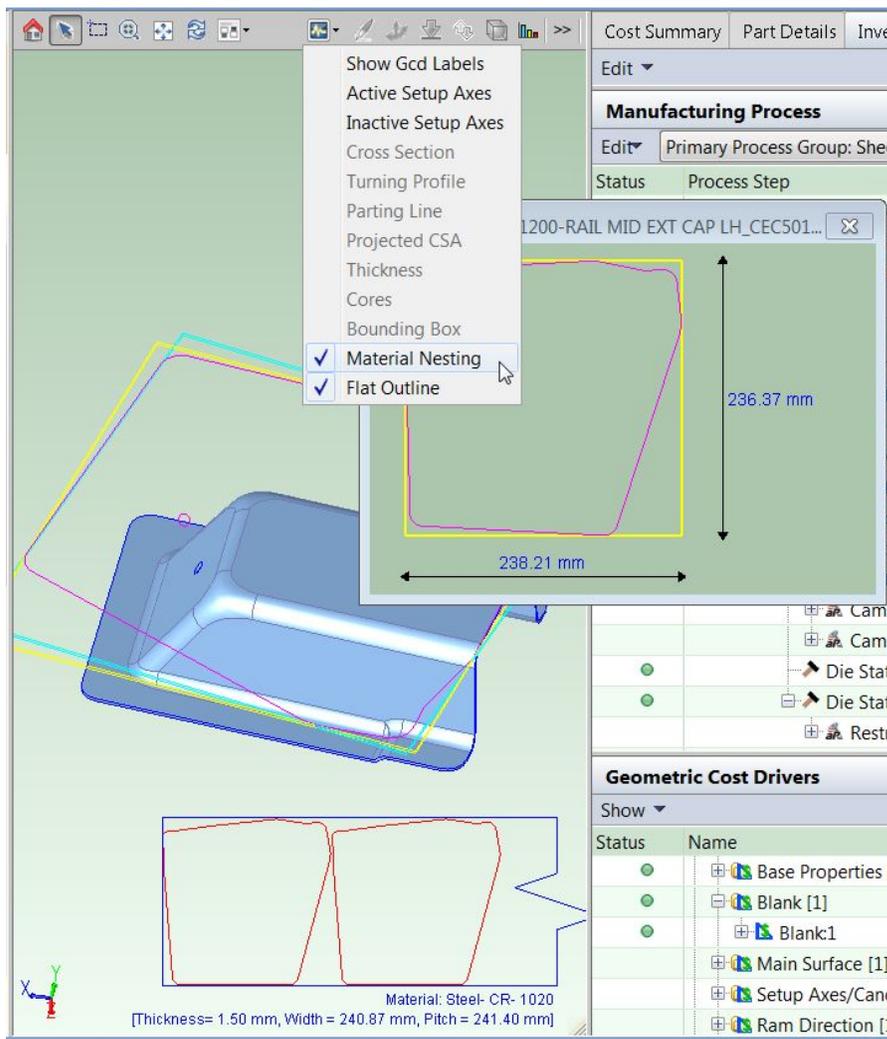
To view the orientation of the blank on the stock, select **Material Nesting** from the Analysis menu in the Viewer toolbar.





See also [Material Utilization and Part Nesting for Transfer Die](#).

You can display the flat pattern head on, in a separate window, together with its associated SER, by selecting **Flat Outline** from the Analysis menu in the Viewer toolbar.



Blank SER/SWER Length and Width Versus Blank Pitch and Coil Width

It is very important to distinguish between the following rectangles that enclose the flattened part:

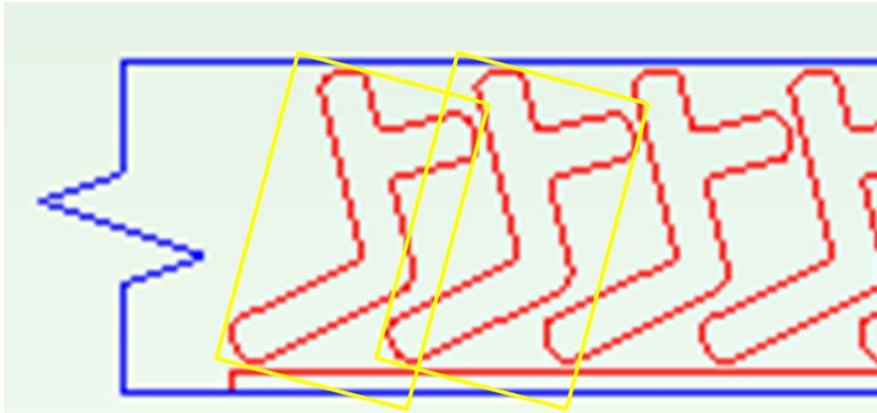
- Blank's SER or SWER: these rectangles' dimensions are independent of the blank's orientation on the stock coil or sheet; that is, **SER Length**, **SER Width**, **SWER**

- Length**, and **SWER Width** do not change if the blank's nesting or orientation change.
- Nested blank's extent rectangle: this is a rectangle that
 - Contains all of the flattened part
 - Has sides that are each either parallel or perpendicular to the sides of the material stock.
 - Encloses extra material around the flattened part for various purposes, such as carrier strips and cutting strips.

The dimensions, blank pitch and coil width, of this extent rectangle *do* depend on the blank's orientation on the coil; these dimensions can change if the orientation changes. See [Blank Pitch](#) and [Coil Width](#).

Some users might be used to using the term “blank” to refer to the extent rectangle described above; but this is *not* what the Blank GCD represents. The Blank GCD represents the flattened part, whose **SER Width** and **SER Length** are independent of nesting and orientation.

The figure below shows nested Blanks oriented on the stock coil. The Blank SERs are shown in yellow.



Flattening for Transfer Die

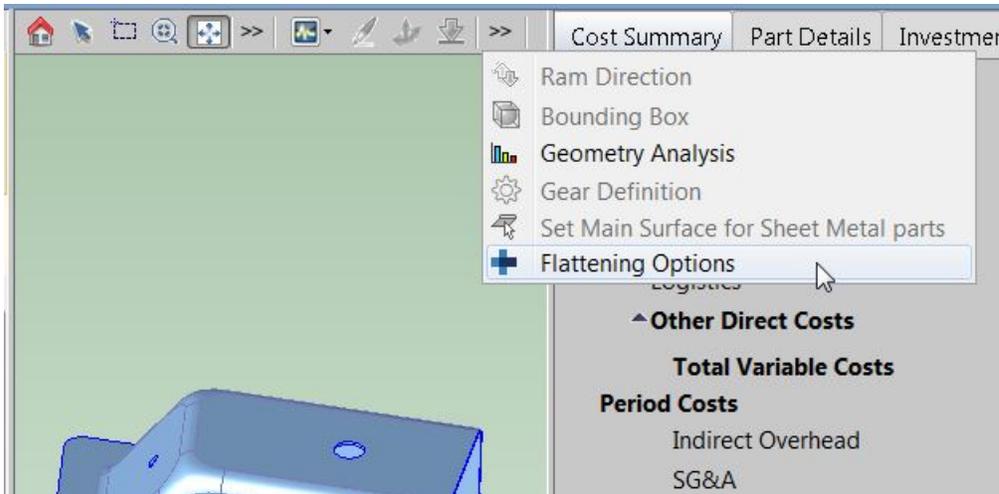
aPriori provides two alternative methods for determining the outline of the flattened part, finite element analysis (FEA)-based flattening and geometric flattening:

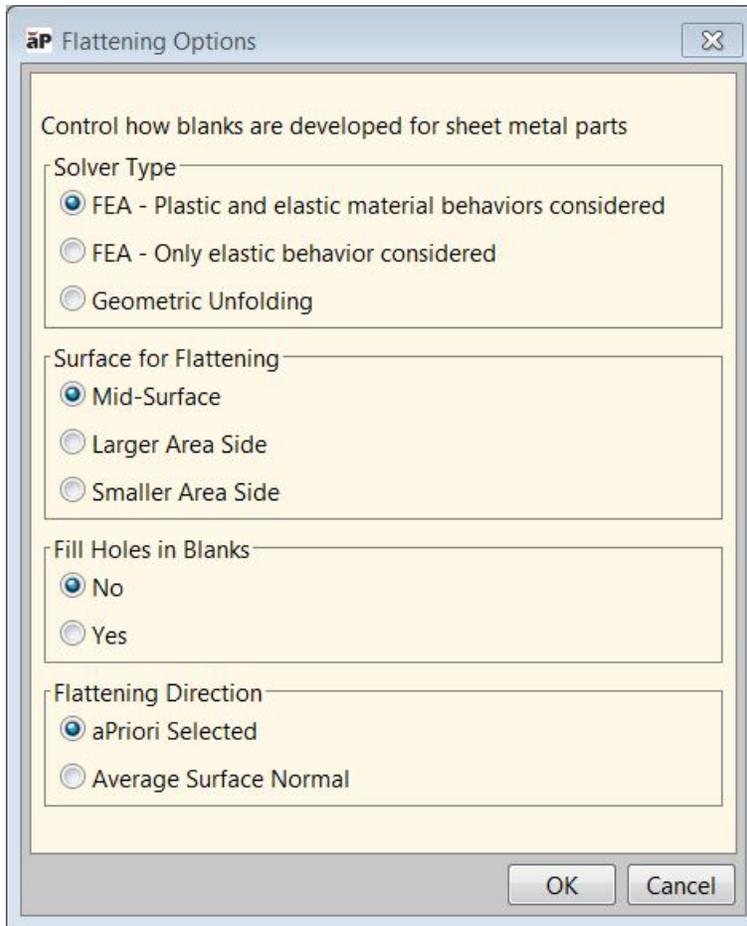
- FEA flattening:
 - Analysis is based on a forming simulation which uses a finite element analysis derived from the part's CAD model and the properties of the selected material.
 - More accurate than geometric flattening for formed and drawn automotive components and similar complex stampings.
 - Generally slower than geometric flattening (very complex parts sometimes require more than one minute to flatten, although the great majority require far less time).
- Geometric flattening:
 - Analysis is based on unfolding of CAD model geometry, and neither takes into account material properties nor simulates the forming process.

- Accurate for “mostly developable” parts, that is, parts consisting primarily of flat planar surfaces and simple bent or rolled surfaces, with a few small, isolated deformed features like gussets and stiffening beads. These types of parts are common in the agriculture/construction equipment and hi-tech industries.
- Generally faster than FEA flattening.

FEA flattening is used by default in starting point VPEs. VPE administrators can customize this default with the site variable **flatteningSolverType**.

For a given part, you can override the default flattening method, or configure FEA flattening, with the Flattening Options dialog, which is available from the Viewer toolbar.





The dialog provides the following options:

- **Solver Type:**
 - FEA – Plastic and elastic material behaviors considered: takes into account both the elasticity-related material properties (including Young’s modulus and Poisson’s ratio) and the plasticity-related material properties (including K, the strain-hardening coefficient, N, the strain-hardening exponent, and R, the Lankford parameter, average) . This is the default in starting point VPEs.
 - FEA – Only elastic behaviors considered: takes into account only the elasticity-related material properties (including Young’s modulus and Poisson’s ratio). Because only elastic behavior is modeled, blank size estimates are slightly larger with this option than with the “Plastic and elastic” option. Some users prefer this approach as it is slightly more conservative for estimating material usage and costs.
 - Geometric Unfolding: Select this if you don’t want to use FEA flattening.

The **Flattening Method** property of the Blank GCD indicates the method used for the most recent geometry extraction. Its possible values are FEA_PLASTIC, FEA_ELASTIC, GEOMETRIC_UNFOLDING.

Geometric Cost Drivers			
Status	Name	O... Name	Property Result
●	Component	Num Edges	17
●	Base Properties [1]	Num Sharp Corners	-
●	Blank [1]	Straight Length (mm)	1,138.65
●	Blank:2	Flattening Method	FEA_PLASTIC
●	Edge:79	Worst Peninsular Ratio	0.00
●	Edge:80	Worst Peninsular Rati...	0.00
●	Edge:81	Requested	<auto-select>
●	Edge:82	Selected	Blanking / Direct Trimmin...

VPE administrators can customize the default solver type with the site variable **flatteningSolverType**.

- Surface for Flattening: applies to FEA flattening only. FEA flattening proceeds by imposing a mesh on an overall surface of the part. The mesh serves to divide the part into a large but finite number of discrete elements.
 - Mid-Surface: specifies that the mesh should be imposed midway between one side of the part material and the other side of the part material. A mid-surface mesh basically represents the neutral surface of the part. This is the default in starting point VPEs.
 - Larger Area Side: specifies that the mesh should be imposed on the larger-area side of the part material.
 - Smaller Area Side: specifies that the mesh should be imposed on the smaller-area side of the part material.

VPE administrators can customize the default surface for flattening with the site variable **flatteningSurface**.

- Fill Holes in Blanks: applies to FEA flattening only.
 - No: specifies that the mesh (see Surface for Flattening, above) should not be applied to portions of the material surface that will be removed to form a hole. This is the default in starting point VPEs.
 - Yes: specifies that the mesh (see Surface for Flattening, above) should be applied to portions of the material surface that will be removed to form a hole.

VPE administrators can customize the default with the site variable **flatteningFillHoleMethod**.

- Flattening Direction: applies to FEA flattening only.
 - aPriori Selected: specifies that the flattening calculation should be based on the ram direction chosen by aPriori—see [Ram Direction for Transfer Die](#). This is the default in starting point VPEs.
 - Average Surface Normal: specifies that the flattening calculation should be based on a ram direction that is the average direction of the normal to the part's surfaces.

VPE administrators can customize the default flattening direction with the site variable **flatteningDirection**.

VPE Administrators also can customize the FEA flattening behavior with the following site variables:

- **flatteningInitialStrainValue** (0.002 in starting point VPEs): for FEA flattening, specifies the strain present in the material before outside forces and loads are applied.
- **flatteningTimeoutSeconds** (600 seconds in starting point VPEs): determines how long FEA flattening will run before timing out; if FEA flattening times out or fails for any reason, an FEA-failure message appears in the Viewer, and geometric flattening is used instead. A value of 0 indicates no timeout—FEA flattening will run indefinitely.

As mentioned above, FEA flattening takes into account material properties, including the following:

- Density
- Young's Modulus
- Poisson's Ratio, K (strain-hardening coefficient)
- N (strain-hardening exponent)
- R (Lankford parameter, average).

Materials in starting point VPEs specify these properties. If your VPE includes a material that doesn't specify these properties, aPriori uses the following default values based on material type:

Material Type	Young's Modulus (MPa)	Poisson Ratio	K (strain-hardening coefficient, MPa)	N (strain-hardening exponent, MPa)	R (Lankford parameter, average)
Aluminum	69000	0.33	341.1	0.21	0.7
Copper	115000	0.33	317	0.54	0.99
Galvanized Steel	207000	0.28	543	0.21	0.99
Stainless Steel	207000	0.28	1426	0.502	1
Steel	207000	0.28	0.28	479.3	1.345

If the material type is not one listed in the table above, the entries for Steel are used.

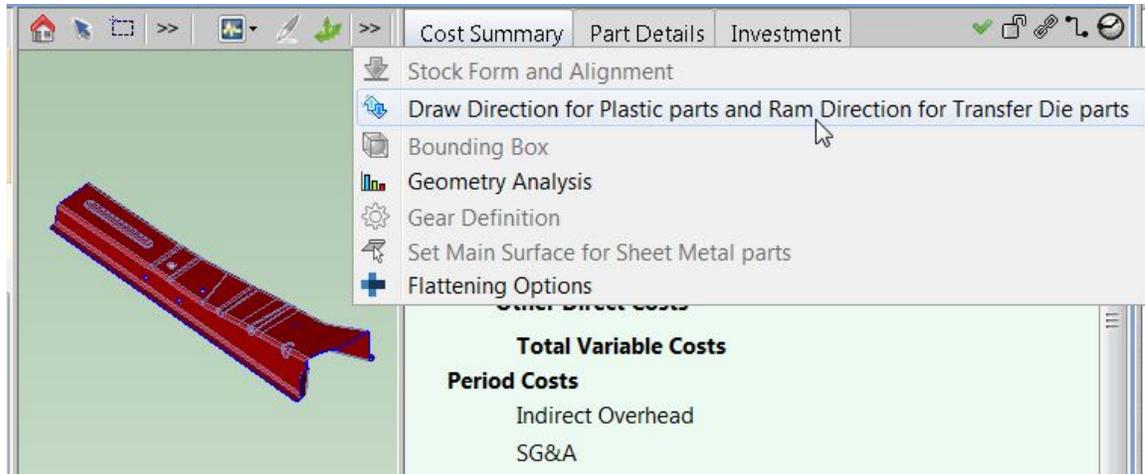
Ram Direction for Transfer Die

The RamDirection GCD represents the direction from which the ram approaches the workpiece. aPriori chooses a part-relative ram direction as described in [How the Default Ram Direction is Chosen](#). This choice attempts to minimize undercuts and provide access to the part's primary form. You can override aPriori's choice as described in [Overriding the Default Ram Direction](#).

Overriding the Default Ram Direction

You can override aPiori's choice of ram direction by using the Ram Direction tool, , in the Viewer. Follow these steps:

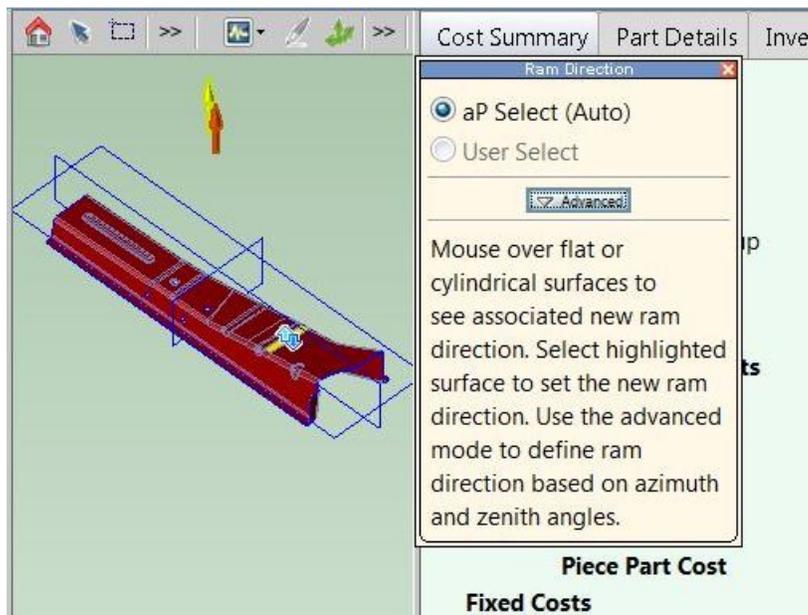
- 4 Select the Ram Direction tool from the Viewer toolbar.



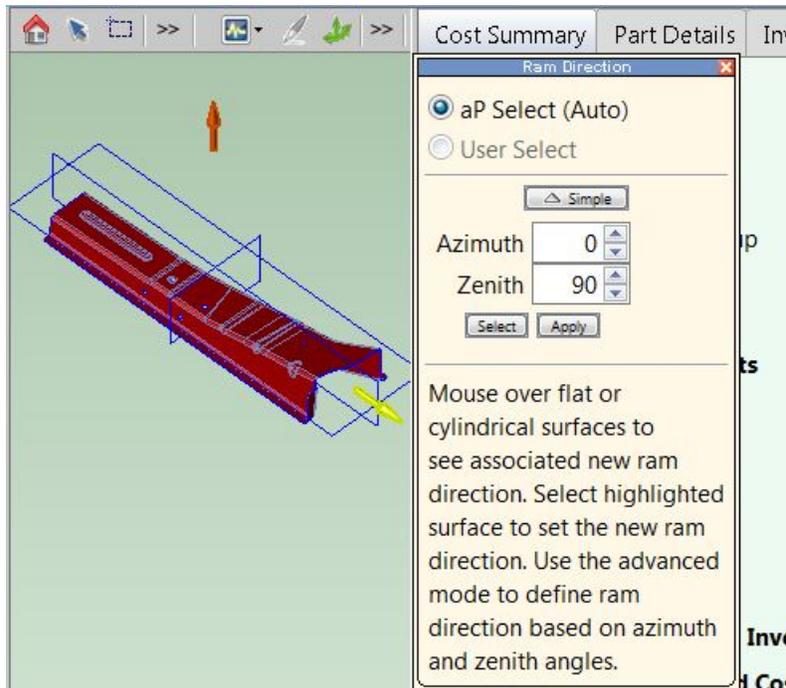
- 5 An orange arrow indicates the ram direction. The arrow points to the region of space *from* which the ram approaches; the direction in which the ram moves as it approaches the part is the opposite of the ram direction.

When you hover over a flat or cylindrical surface, the Viewer highlights the surface, and a yellow arrow indicates the candidate ram direction associated with that surface.

Click a highlighted surface to set the new ram direction.



You can also use the Advanced mode of the Ram Direction tool in order to set the ram direction by specifying Azimuth and Zenith.



How the Default Ram Direction is Chosen

In order to choose a ram direction, aPriori identifies a number of candidate directions:

- Direction of each (simple or complex) hole.
- Direction associated with the part's largest, accessible surface

The direction associated with the part's largest accessible surface is a direction that provides the best accessibility to the maximal group of adjacent surfaces that has the following characteristics:

- Group includes the part's largest, accessible surface.
- Every surface in the group is accessible from the same direction.

The direction that provides best accessibility to such a group is the direction that maximizes the projected area of the surfaces onto a plane perpendicular to the direction.

(Note that a group of adjacent surfaces is a group such that for any pair of surfaces in the group, there is a path from one surface to other that never leaves the group.)

In order to pick the ram direction from among the candidate directions, aPriori also associates such a maximal group of surfaces with each hole. That is, for each hole, it finds the maximal group of adjacent surfaces that has the following characteristics:

- Group includes the surface that contains the hole
- Every surface in the group is accessible from the same direction.

To select the ram direction, aPriori weighs the following factors for each candidate direction:

- Area of the projection of the candidate's associated surfaces onto a plane perpendicular to the candidate. Larger areas are favored.
- Area of the holes that are parallel to the candidate. Larger areas are favored.

- Projected area of all the part's planar surfaces that are perpendicular to the candidate. Larger areas are favored.
- Area of the surfaces that are *not* in the candidate's associated group. Smaller areas are favored.

The selected direction actually represents a pair of opposite directions (such as East/West or Up/Down). aPriori selects one element of the pair of opposites based on the following factors:

- Cross-sectional area (parallel to the ram direction) of the part's SER below and above the part. If one area exceeds about twice the other area, the ram direction points towards the smaller volume
- Side-accessible projected area of the flange surfaces that wrap around the part. This is the area of the projection of the outside flanges onto planes that contain the ram direction. If the projected area of one side of the flange surfaces exceeds the projected area of the other side of the flange surfaces by about 10% or more, the side with larger projected area faces the ram direction.

Main Surface for Transfer Die

The MainSurface GCD represents a portion of the part that retains a relatively stable orientation relative to the press table all throughout the stamping process, except during active tipping (which the model does not currently support). For transfer die, a pad that spans the main surface holds the part in place during operations such as drawing and pad & wipe. aPriori chooses a main surface as described below. The choice attempts to minimize expensive tooling and minimize the number of stations required to make the part.

The MainSurface GCD consists of the group of associated surfaces that has the following characteristics:

- No surface in the group is part of any bend.
- No surface in the group is nearly vertical; that is, the normal to each surface in the group is within 60 degrees of the ram direction (see [Ram Direction for Transfer Die](#)).
- Every surface in the group is accessible from the ram direction.

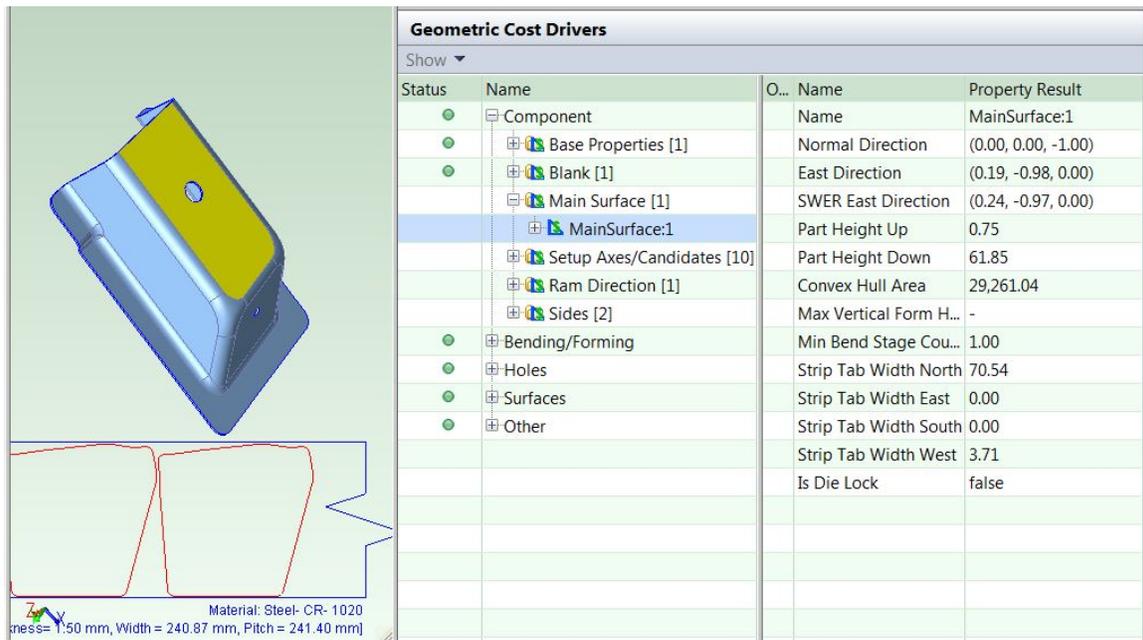
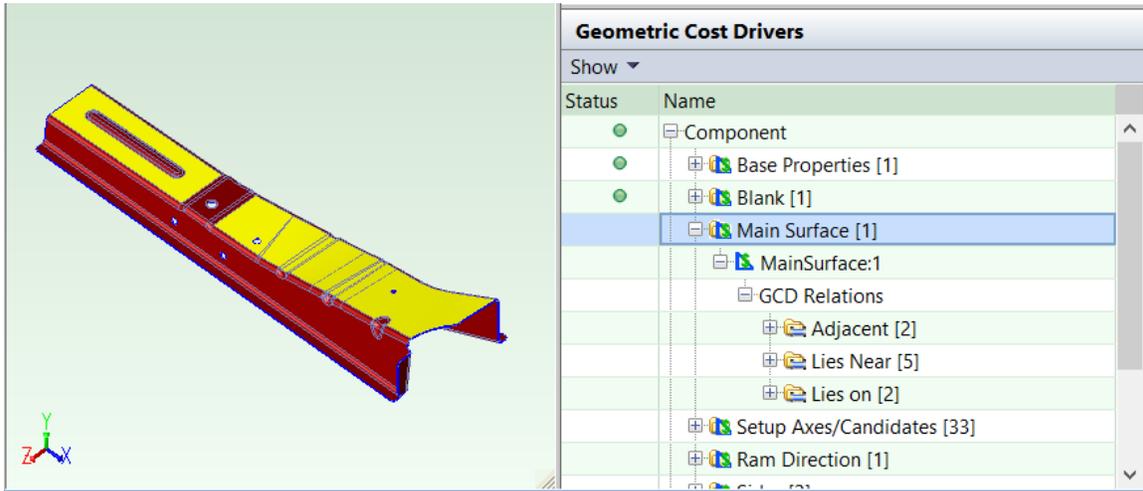
aPriori identifies multiple main-surface candidates that have the above characteristics, and then selects one of the candidates by weighing the following considerations:

- Height of the surfaces, measured from the bottom of the part bounding box. Higher candidates are favored.
- Area of the surfaces; or, more precisely, the area of the projection of the surfaces—including holes—onto a plane normal to the ram direction. Larger candidates are favored.
- Distance of the surfaces from the centroid of the part. Closer candidates are favored.

Note that surfaces within a given group may be separated into disjoint islands by deformations in the part.

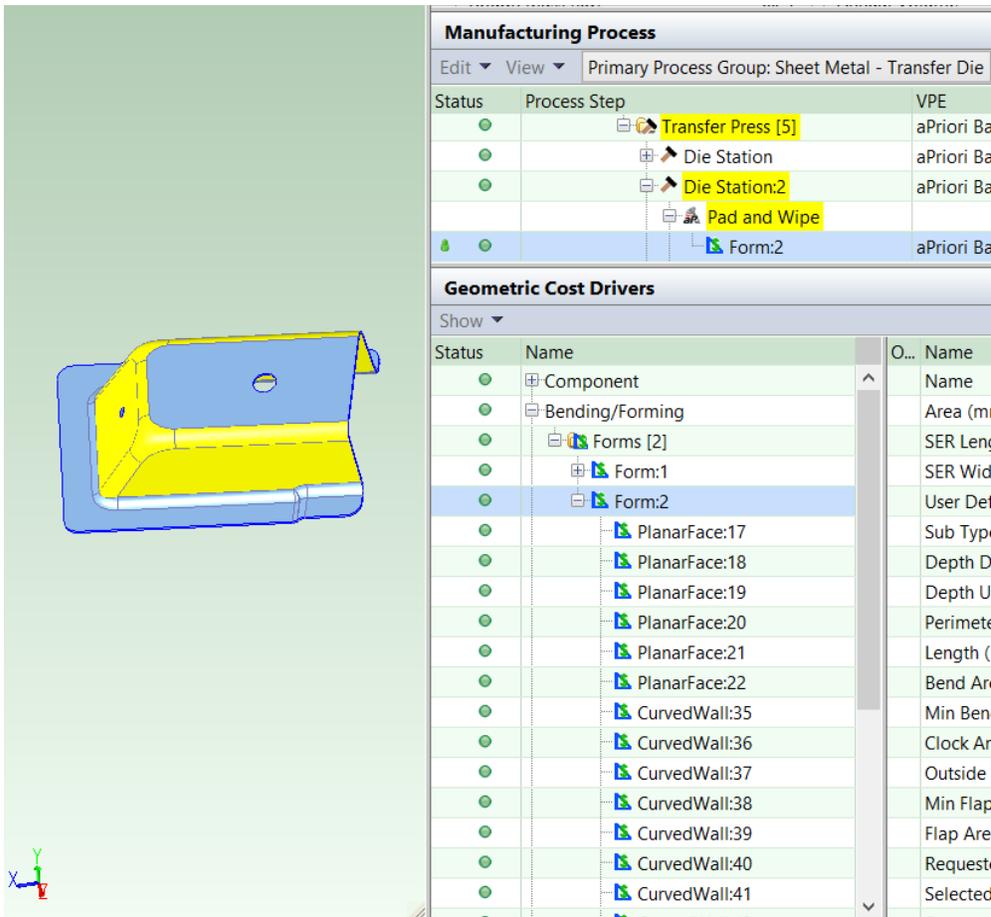
The XY orientation of the surface is determined within the cost model. You can override aPriori's choice of ram direction (which affects main surface choice) by using the Ram Direction tool in the Viewer. See [Ram Direction for Transfer Die](#).

The images below show the main surface in yellow.

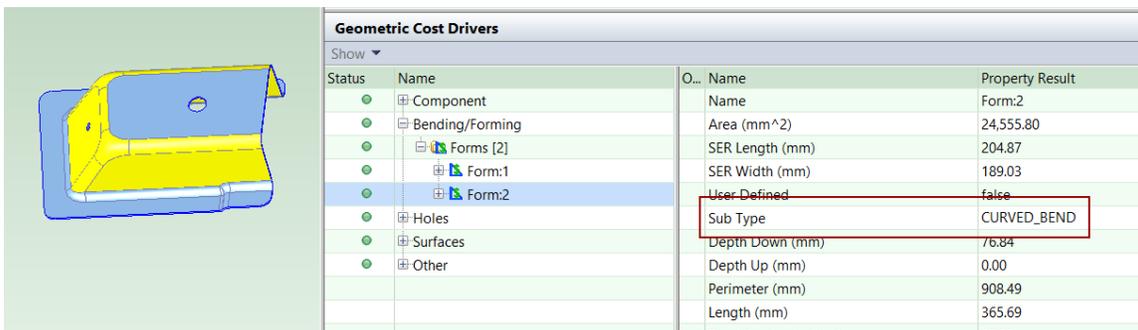


Form GCD

Forms are identified by geometry extraction as collections of surfaces that can be created with a single operation such as drawing, crash forming, pad and wipe, or bending.



Geometry extraction also classifies each form as either a CURVED_BEND or EMBOSS. The classification is reflected in the SubType property listed in the Geometric Cost Drivers pane.

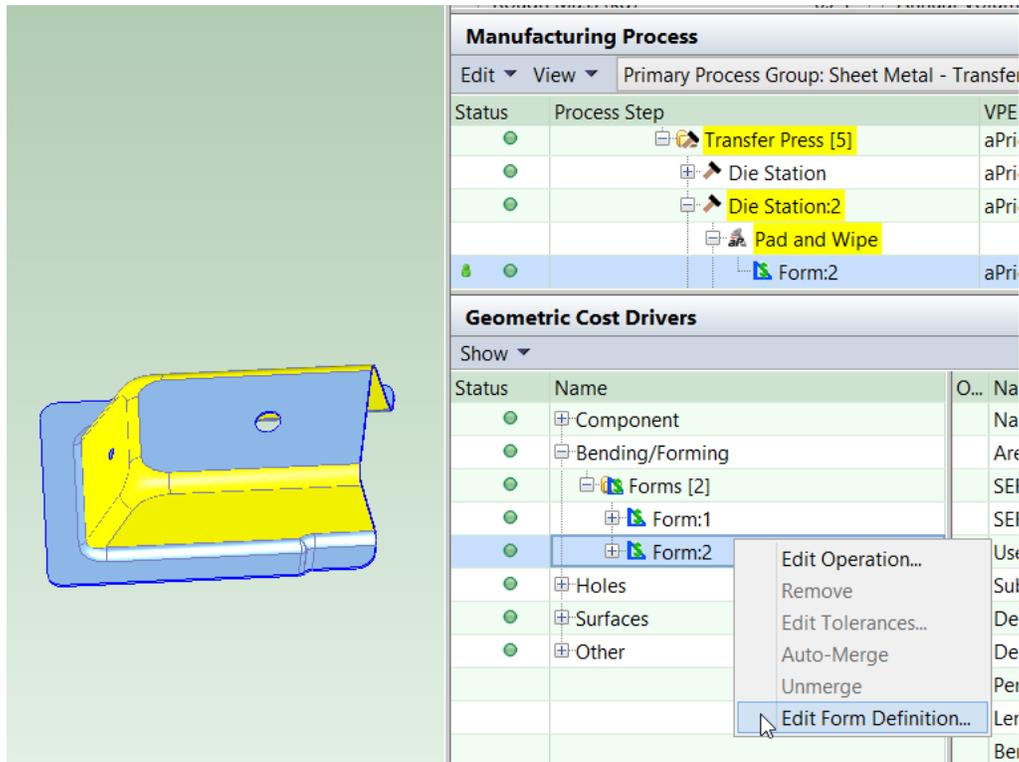


Creating and Editing Forms

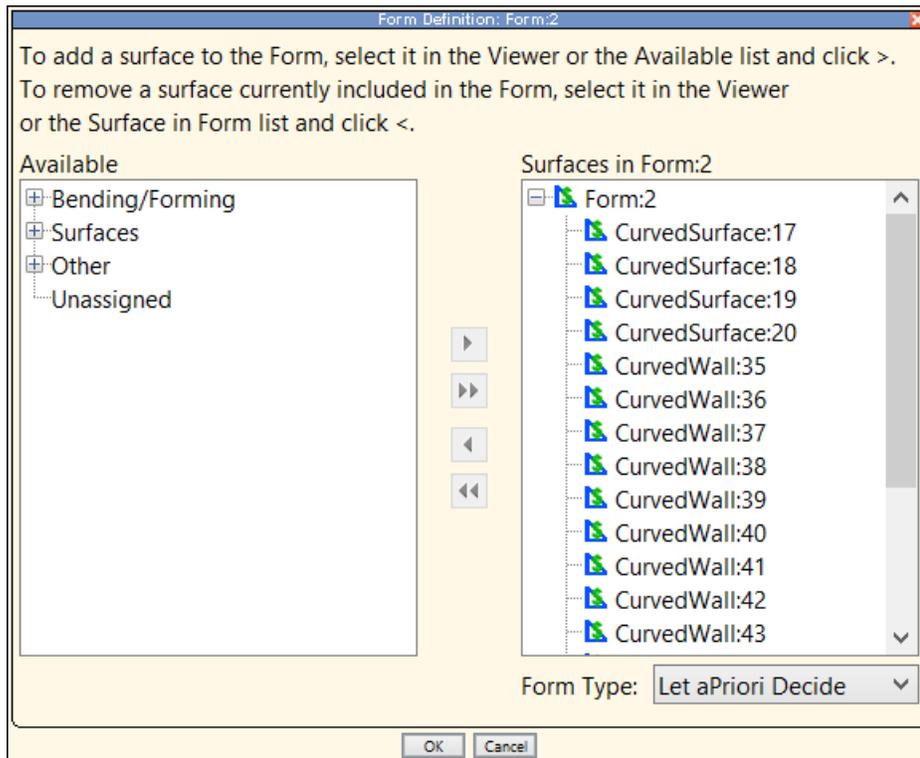
You can override the extracted surface groupings by using the Form Definition dialog, provided you are connected to your part's CAD model.

To edit an existing form:

- 6 Right click on the form in the Geometric Cost Drivers pane and select **Edit Form Definition**:

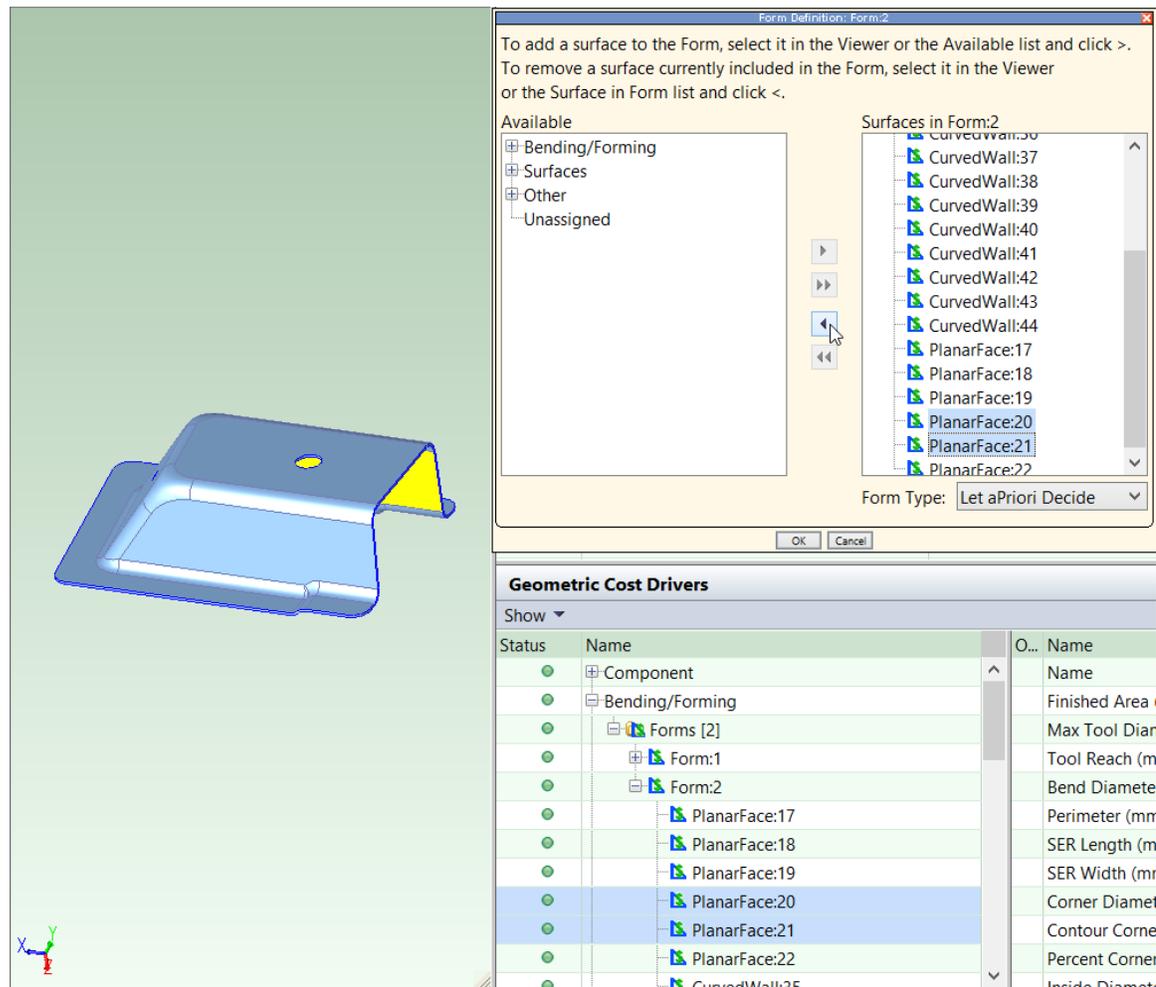


The Form Editor appears:



- 7 Select surfaces in the Viewer or in the dialog, and use the arrows,  and , to move them between the **Available** column and **Surfaces in Form** column. Note that when you select a surface, the opposite surface (directly on the other side of the

blank) is automatically selected. Pairs of opposite surfaces are listed in the Geometric Cost Drivers pane under the Parallel relation, under GCD Relations.



You can use the double arrows, **▶▶** and **◀◀**, to move all a form's surfaces between the **Available** column and **Surfaces in Form** column—select a form GCD in one of the columns and click a double arrow.

Note that the form must not include any disconnected surfaces, that is, any two surfaces in the form must be connected to one another by a sequence of surfaces all of which are in the form.

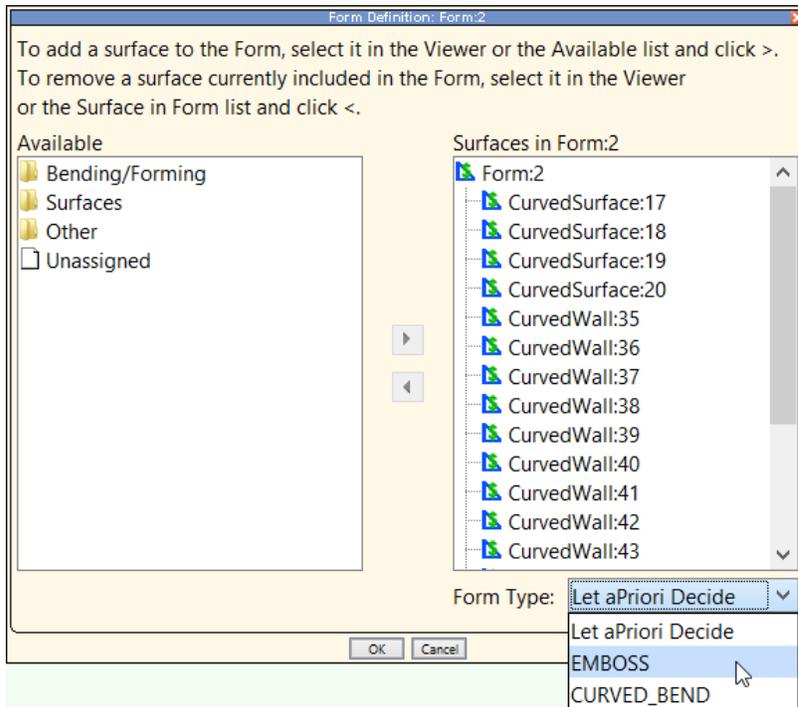
8 Re-extract geometry.

To create a new form:

- 9 Click the Form Definition tool, , in the toolbar. The Form Definition dialog appears.
- 10 In the Viewer or in the left pane of the Form Definition dialog, select the forms that you want to include in the new form, and then use the arrow to move them to the **Surfaces in New Form** column.
- 11 Re-extract geometry.

Modifying the Subtype of a Form

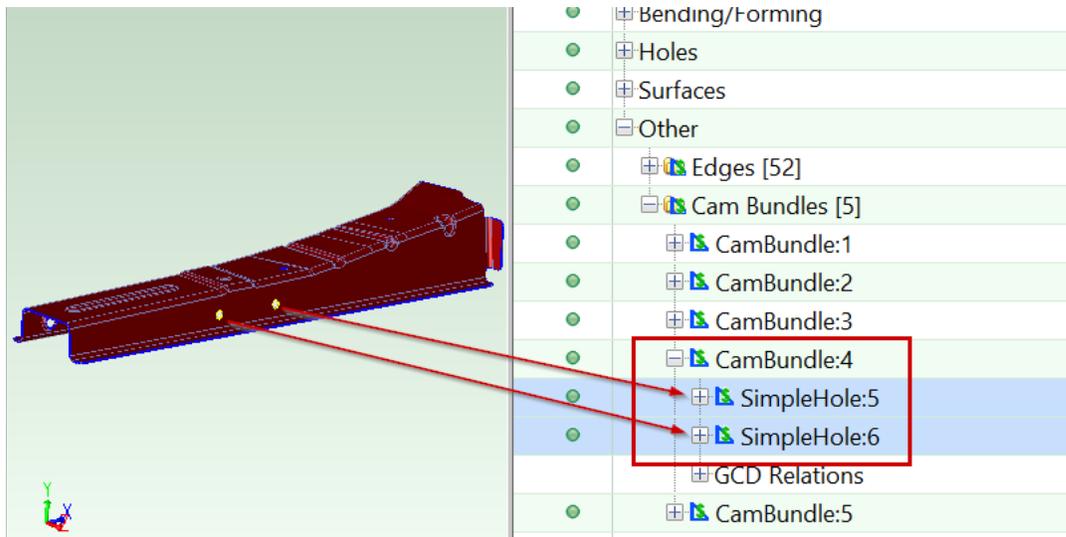
You can change a form's subtype by editing the **SubType** property in the Geometric Cost Drivers pane, or by using the Form Definition dialog, provided you are connected to your part's CAD model:



Be sure to re-extract geometry after you change the subtype.

Cam Bundling for Transfer Die

A cam is required for features that must be accessed from the side, including bends, lances, edges (for trimming), and holes (for piercing). The same cam can do both trimming and piercing, and can generally handle both multiple edges and multiple holes, as long as all the features are accessible from the same direction. Holes and/or segments handled by the same cam are grouped together into CamBundle GCDs. The Geometric Cost Drivers pane allows you to see which features each cam handles.



The following cost model variables constrain the grouping of GCDs into bundles:

- **minSpaceWithinBundle**: specifies smallest allowable distance between bundled GCDs.
- **maxBundleWidth**: specifies the maximum allowable width of a CamBundle
- **maxBundleGap**: specifies the maximum allowable horizontal distance between bundled GCDs.

For each CamBundle, the cost model assumes the use of one of the following types of cam:

- Standard cam: mounted on the lower die shoe.
- Aerial cam: mounted on the upper die shoe.

In starting point VPEs, for cam trimming or cam piercing operations on a given feature, an aerial cam is used if the feature can be accessed from a direction that is less than or equal to 75 degrees from the ram direction. You can customize this threshold with the cost model variable **aerialCamAngleUpperThreshold**. An aerial cam is also assumed when a cam is required to reach across the part in order to avoid pushing scrap onto the part, and the required reach exceeds that of a typical standard cam (defined by the cost model variable **defaultStandardCamWorkTravel**--60mm in starting point VPEs). In other cases, standard cams are assumed.

You can override aPriori's assessment of the number, sizes, and types of the cams required for a part, and use process setup options to specify the number of various sizes of standard and aerial cams.

Note that aerial cam units are itemized separately from standard cam units in the Investment tab and the Transfer Die tooling report, as typically they are more expensive than standard cam units.

See also [Cam Piercing](#) and [Edge Trimming](#).

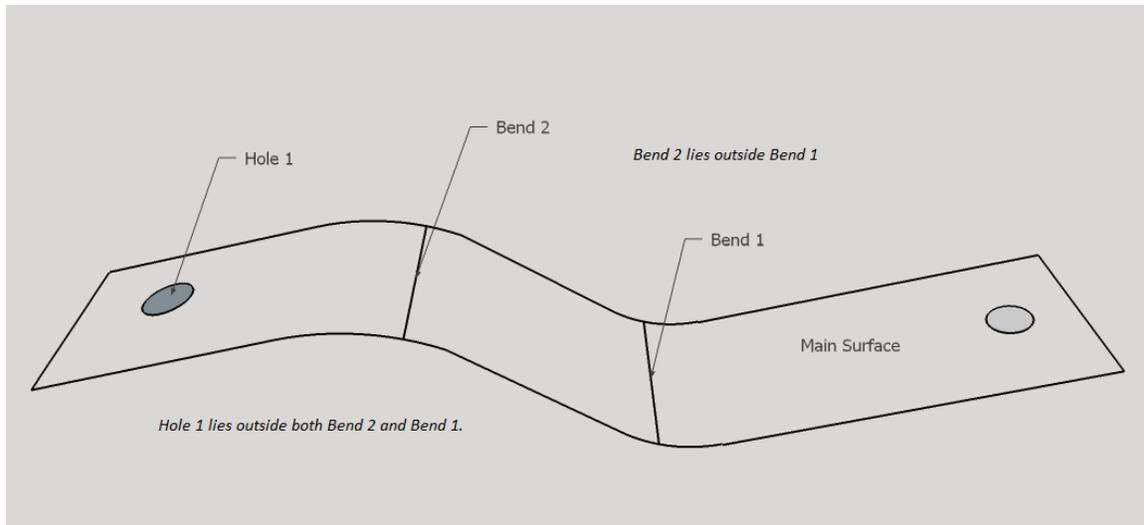
LIES_NEAR Relation

Some precedence rules and bundling logic refer to the LIES_NEAR relation. Holes that are too near to each other cannot be pierced or tapped on the same die station. In

addition, holes or edges that are too close to each other cannot be included in the same cam bundle. See also [Cam Bundling for Transfer Die](#).

LIIES_OUTSIDE Relation

Several feasibility, compatibility, and precedence rules refer to the **LIIES_OUTSIDE** relation (under **GCD Relations** in the Geometric Cost Drivers pane). If one GCD, *feature-1*, lies between another GCD, *feature-2*, and the main surface, we say that *feature-2* lies outside of *feature-1*, that is, there is a **LIIES_OUTSIDE** relation whose value for **First** is *feature-2* and whose value for **Second** is *feature-1*.



Surface-only CAD Models for Transfer Die

In addition to solid CAD models, the Transfer Die and Sheet Metal process groups support surface CAD models, which represent surfaces only, rather than solid geometry. Surface models typically model one side of stamped or soft tooled metal component.

When you use a surface-only model, you must enter the intended part thickness into the **Blank Thickness** field of the Cost Guide. The surface model together with the specified thickness allow aPriori to, in effect, extrapolate a solid model of the part, and then extract geometry and perform costing just as it would with a solid CAD model as input.

* Cost Guide

1 Production Scenario	2 GCD Tolerances	3 Process and Machine Options
-----------------------------	------------------------	--

Recently used settings

1.1 Basic Options

Process Group:
Sheet Metal

VPE:
aPriori USA

Process Routing:
 with aPriori-computed routing
 with optional process overrides

Material:
Steel, Cold Worked, AISI 1020

Blank Thickness:
mm

Volume and Batch Size:
5,500 annually for 5.00 yrs

You can also specify blank thickness for surface models with the aPriori Bulk Costing interface: right-click on the desired parts (rows) and select **Production Inputs**.

The geometry and costing results for a surface-only model of a part are generally identical or extremely similar to the results for a solid model of the same part. But because information is missing from the surface-only model (even with the addition of a thickness value), some geometric processing might differ slightly.

One type of information that is missing from a surface model is the exact shape produced by the cuts that create the holes and edges of the blank. In these situations, aPriori assumes that the cuts are true, at 90 degrees to the surface.

For example, an elliptical opening in a model (either solid or surface) indicates a hole GCD, but the information in the surface model is not sufficient to determine whether the walls of the hole are cylindrical; so aPriori assumes that the hole is a complex hole (with non-cylindrical walls and an axis perpendicular to the part surface) rather than an angled simple hole (with cylindrical walls and an axis oblique to the part surface). The additional information provided by a thickness value still leaves this under-determined.

Similarly, a surface model lacks sufficient information to determine whether an edge is chamfered.

Note also that the GCD Area and Volume properties for a surface-only model of a part might differ slightly from the same properties for a solid model of the same part. This is because the information in the surface-only model under-determines the effects of bends and curves on volume and surface area calculations. So, in starting point VPEs, costs that depend heavily on surface areas and volumes (for example, costs for heat treatment and surface treatment) might differ slightly between surface-only and solid models.

Note that if you enter a value into the **Blank Thickness** field for a solid CAD model, aPriori ignores it, and issues a message indicating that thickness will be derived from the solid model rather than from the user-entered value. If your company does not use surface-only models, you can remove the **Blank Thickness** field from the Cost Guide if you wish—see the *aPriori System Administration Guide* for information on customizing the Cost Guide.

GCD extraction for surface models can be disabled with the aPriori property `apriori.enable.surface.models.sheetmetal`—see the *aPriori System Administration Guide* for more information.

Tooling for Transfer Die

This section covers the following topics:

- Tool Life for Transfer Die
- Tooling Bill of Materials for Transfer Die
- Customizing Tooling Costs for Transfer Die

See also [Tooling Overview for Transfer Die](#).

Tool Life for Transfer Die

For Transfer Die and Offline Blanking, the tooling model estimates the number of parts that can be produced with a given tool before it wears to the point that it needs to be replaced. Based on that estimate, the cost model determines the number of tools required to manufacture the production volume specified in the Production Scenario tab of the Cost Guide, and accounts for that number of tools in total hard tooling cost.

Tool-life estimation is based on part material, and adjusted for tool material and tool coating type, as follows:

- 12 To determine an unadjusted value for the number of parts that can be produced by a single tool, the cost model looks up this number by part material in the lookup table **tblToolLife**.

Material Type	Num Parts Per Tool
Aluminum	17,500,000.00
Copper	17,500,000.00
Galvanized Steel	3,000,000.00
Heat Resistant Super Alloys	625,000.00
Low-Alloy Steel	3,000,000.00
Stainless Steel	750,000.00
Steel	3,000,000.00
Titanium	100,000.00
Unalloyed Steel	3,000,000.00

- 13 The result is then adjusted for mold material by multiplying it by the tool shop property **Tool Life Factor** for the current mold material (see [Tooling Material](#)).

- 14 That result is then adjusted for mold coating by multiplying it by the **Tool Life Improvement Factor** looked up in the table **tbiToolCoating** by coating type (see **Coating of Tooling**).

Coating Cost Factor (USD / kg)	Coating Type	Tool Life Improvement Factor
0.00	None	1.00
1.90	Tribo-coating	1.10
2.80	Electroless Nickel	1.40
3.50	Electroless Teflon	1.70
4.10	Nitrided Steel	1.90
4.40	Electroplated Chromium	2.00
6.90	Plasma Sprayed	3.00
18.20	PVD TiN	7.20
19.10	CVC TiC	7.50
26.60	DuplexVariantic	14.40

For a given costing, either the formula Dependencies or Investment tab displays the number of tools assumed by tooling cost calculations.

Tooling Bill of Materials for Transfer Die

The Transfer Die Process tooling model provides an itemized tooling cost estimate, including a detailed tooling BOM. Individual estimates for tooling cost per station including material and labor for each station are provided.

An itemized estimate for the following output variables can be found in the **Investments** tab:

- Properties
 - Blank Pitch
 - Blank Thickness
 - Blank Width
 - Required Shut Height
 - Stock Length
 - Tooling Tryout Hours
- Component Quantity
 - aerial cam unit - 1000 Series
 - aerial cam unit - 1200 Series
 - aerial cam unit - 150 Series
 - aerial cam unit - 300 Series
 - aerial cam unit - 600 Series
 - aerial cam unit - 800 Series
 - bending heal - heal
 - bending heal - wear plate
 - binder
 - binder - guide pin assy
 - blank adapter

- blank gage - standard
- blank gage - with sensor
- blank holder
- bottom plate
- cam gas spring
- cam slug deflector
- cam stripper - spool
- cam stripper - stripper
- cam unit - 1000 Series
- cam unit - 1200 Series
- cam unit - 150 Series
- cam unit - 300 Series
- cam unit - 600 Series
- cam unit - 800 Series
- die block - adapter
- die block - block
- die button
- draw pad balance block
- gas spring flanged
- guide pin assy
- keeper block
- pad balance block
- parallels - bottom
- parallels - top
- punch - bend - bending
- punch - bend - cam bending
- punch - blank
- punch - cutoff - insert
- punch - cutoff - insert holder
- punch - form - embossing
- punch - form - forming
- punch - pierce - custom
- punch - pierce - standard
- punch - scoring
- punch - trim
- punch adapter
- punch backing plate - pierce - custom
- punch retainer - pierce - custom
- punch retainer - pierce - standard
- stamp - operation level
- start pin
- stock guide - additional

- stock guide - lead
- stop block - block
- stop block - pad
- stripper - guide pin assy
- stripper - stripper
- stripper pin assy
- stripping window
- tap - standard
- tapping - in-die cam tapping unit
- tapping - in-die tapping unit
- thrust key
- trim die heal - heal
- trim die heal - wear plate
- Labor
 - Assembly Cost
 - Assembly Hours
 - CNC Machining Cost
 - CNC Machining Hours
 - CNC Prgm Cost
 - CNC Prgm Hours - 2D
 - CNC Prgm Hours - 3D
 - CNC Prgm Hours - Holemaking
 - CNC Prgm Hours - Wire EDM
 - Design Cost
 - Design Hours
 - Total Machining Setup Cost
 - Total Machining Setup Hours
 - Wire EDM Cost
 - Wire EDM Hours
- Material Cost
 - cam units - total cam unit cost
 - die level - blank adapter
 - die level - blank gage - standard
 - die level - blank gage - with sensor
 - die level - bottom plate
 - die level - die shoe lower
 - die level - die shoe upper
 - die level - gas spring - flanged
 - die level - guide pin assy
 - die level - ident stamps
 - die level - in-die cam tapping unit
 - die level - in-die tapping unit

- die level - keeper block
- die level - pad balance block
- die level - parallels bottom
- die level - parallels top
- die level - start pin
- die level - stop block
- die level - stop block pad
- die level - stripper
- die level - thrust key
- die level - trim die heal - heal
- die level - trim die heal - wear plate
- station level - bending heal - heal
- station level - bending heal - wear plate
- station level - blank holders
- station level - cam gas spring
- station level - cam slug deflector
- station level - cam stripper
- station level - cam stripper spool
- station level - die block adaptors
- station level - die blocks
- station level - draw pad balance block
- station level - punch adapter
- Total Tool
 - Carrying Cost
 - Coating Cost
 - Freight Cost
 - Gage Cost
 - Heat Treat Cost
 - Labor Cost
 - Material Cost
 - Profit Cost
 - SG&A Cost
 - Tryout Cost
 - Tuning Cost
 - Welding Cost
- Total Tool Cost - Offline Blanking Die

Customizing Tooling Costs for Transfer Die

Following is a selection of some of the important, controllable factors that affect tooling costs:

Post-form Trimming

The cost model assumes that after forming has been performed, direct or cam trimming is required for blank edges that have tight tolerance.

Post-form trimming is triggered for edges whose positional tolerance is tighter than the threshold specified by the cost model variable **edgeTrimmingPositionToleranceThreshold** (2mm in starting point VPEs). If you haven't specified the positional tolerance of an edge, the cost model assumes the tolerance specified by the cost model variable **defaultPositionToleranceEdgeSegment** (1.5mm in starting point VPEs). Note that all tolerances are bilateral; positional tolerance specifies the diameter of the tolerance zone. See also [Die Station 2: Edge Trimming](#), [Direct Piercing](#).

The cost model variable **enableMultiStationTrimming** controls whether trimming is distributed over two die stations (instead of using just a single station) if the trimmed scrap length exceeds a certain threshold. In starting point VPEs, **enableMultiStationTrimming** is set to **false**, so trimming is always contained to a single station. In this case, if the trimmed scrap length exceeds the threshold, additional tooling costs for scrap breakers are incurred instead of the cost of an additional station.

The scrap length threshold is specified by the cost model variable **maxScrapSizeThreshold** (457.2mm in starting point VPEs). This variable limits the size of the scrap pieces produced by edge trimming. If **enableMultiStationTrimming** is **true**, edges longer than the threshold require two edge trimming operations on two separate stations, rather than just one.

See also [Edge Trimming](#), in the Quick Start.

Post-emboss Piercing

The cost model assumes that piercing operations must be performed subsequent to the Embossing operation, for holes that either have tight tolerance or intersect the embossed form. (Piercing is always performed subsequent to drawing.) Piercing after embossing can sometimes increase tooling costs by increasing the number of die stations or requiring a cam for piercing.

Post-emboss piercing is triggered for holes whose positional tolerance is tighter than the threshold specified by the cost model variable **holePiercingPositionToleranceThreshold** (2mm in starting point VPEs). If you haven't specified the positional tolerance of a hole, the cost model assumes the tolerance specified by the cost model variable **defaultGcdPositionTolerance** (1.5mm in starting point VPEs). Note that all tolerances are bilateral; positional tolerance specifies the diameter of the tolerance zone.

See also [Cam Trimming and Piercing](#) below.

Cam Trimming and Piercing

Trimming a blank edge and piercing a hole requires a cam if the feature is not accessible from a direction that is sufficiently close to the ram direction. You can customize what counts as sufficiently close with the cost model variable **maxRamDirectionTangentAngle** (30 degrees in starting point VPEs). See also [Edge Trimming](#), [Cam Piercing](#), and [Cam Bundling for Transfer Die](#).

Scoring, Tapping, Coining, and Shaving

Some operations are performed only if enabled, and can be disabled or enabled by the following setup options:

- Enable SCORING Operations for Bends
- Enable In Die TAPPING operations
- Enable COINING Operations for SimpleHoles
- Enable SHAVING Operations for SimpleHoles

Restriking

In starting point VPEs, restriking is performed on a form if any of the following conditions hold:

- *Material strength*: selected material has a tensile yield strength that exceeds 344.74 N/mm². You can customize this threshold with the cost model variable **matYieldStrengthRestrikeThreshold**.
- *Width-to-depth ratio*: the form's width-to-depth ratio is less than 0.5. You can customize this threshold with the cost model variable **widthToDepthRestrikeThreshold**. The width-to-depth ratio is the **SER Width** divided by the sum of **Depth Up** and **Depth Down**.
- *Depth-to-thickness ratio*: the ratio of the form's depth to the blank's thickness is less than 1000. You can customize this threshold with the cost model variable **depthToMatThicknessRestrikeThreshold**. The depth-to-thickness ratio is the sum of **Depth Up** and **Depth Down** divided by the material thickness.
- *Minimum radius of curvature*: the form's smallest radius of curvature is less than 10 times the blank thickness. You can customize the blank thickness multiplier with the cost model variable **minRadiusOfCurvatureRestrikeThresholdMultiplier**.
- *Surface tolerance*: the tolerance some surface of the form is tighter than 0.5. You can customize this threshold with the cost model variable **minFormSurfaceToleranceRestrikeThreshold**.

Restriking can occur on the same die station along with multiple other operations, provided those operations are not occurring on the surfaces being restruck and do not otherwise interfere with the restriking operation and tooling.

See also [Die Station 3: Restriking](#).

Blank XY Orientation

By default, parts are oriented in the XY plane so as to minimize transfer pitch. You can control the part orientation with the setup options [Blank XY Orientation within the Transfer Press](#) and [Determine Transfer Pitch Based on:](#).

Ram Direction

The choice of ram direction affects tooling cost by requiring or eliminating tooling components (such as lifters for down bends). You can modify the default choice of ram direction with the ram direction tool, , in the Viewer toolbar. See [Ram Direction for Transfer Die](#).

Number of Concurrent Parts

In starting point VPEs, one part at a time is stamped at each station, by default. Stamping two parts concurrently can decrease cycle time, but it can increase tooling

cost. For progressive die, you can control concurrency with the setup option **Number of Concurrent Parts in Transfer Press**.

Die Shoe Dimensions and Spacing

Transfer pitch is the blank pitch—see **Blank Pitch**—plus twice the value of the cost model variable **dieShoeLengthAllowance** (203.2mm in starting point VPEs), plus the value of the cost model variable **interDieSpacing** (25mm in starting point VPEs). Die shoe width (perpendicular to the pitch direction) is the value of the cost model variable **dieShoeWidthAllowance** (304.8mm in starting point VPEs).

Miscellaneous Setup Options

See the following setup options:

- Heat Treat of Die Components
- Plating of Die Components
- Base Tool Material
- Stamp Assembly Qty
- Freight Cost
- Total Carrying Cost
- Total Gage Cost
- Total Welding Cost

You can also specify the number of die stations directly by editing the number of occurrences of the Die Set component-level operation.

Primary Forming for Transfer Die

Primary forming operations create a part's important forms, including:

- The *primary* form, that is, the largest EMBOSS form that is adjacent to the main surface
- Other EMBOSS forms (with no associated Lance GCD) that intersect the primary form or are adjacent to the main surface
- Other EMBOSS forms (with no associated Lance GCD) that are on the main surface and are shallow (in relation to part thickness)
- CURVED_BEND forms that intersect the primary form or are adjacent to the main surface

Following are the operations that perform primary forming:

- Drawing is only performed on a part if either its forms are not too shallow (compared to the aggregated form width) or it has a long flange. For such parts, Drawing is assigned to all the following kinds of forms:
 - The primary form
 - EMBOSS forms that intersect the primary form or are adjacent to the main surface
 - CURVED_BEND forms that are adjacent to the main surface

- For deep primary forms or curved bends, the number of required draws is calculated based on the form width reduction produced by each draw. The lookup table **drawReductionPercentage** lists the percentage of the pre-draw width that remains after a given draw (that is, after the initial draw, first subsequent draw, second subsequent draw, and third subsequent draw) for a given material thickness. See also [High Strength Material Derate Percentage](#).
- Crash Forming is assigned to all the following kinds of forms:
 - Primary forms that are shallow (compared to the aggregated form width)
 - CURVED_BEND forms that are adjacent to the main surface of a part that has a crash-formed primary form
 - EMBOSS forms that are shallow (compared to the aggregated form width), provided the primary form is crashed formed
 - EMBOSS forms on the main surface that are shallow (in relation to part thickness), provided the primary form is crash formed
 - Pad and Wipe is assigned to a form only if the part's primary form is not assigned to Drawing or Crash Forming (or the form has no primary form). For such a part, Pad and Wipe is assigned to the following kinds of forms:
 - Downward CURVED_BEND forms that are adjacent to the main surface
 - EMBOSS forms on the main surface that are either up features or are shallow (in relation to part thickness)

The following provides the cost model's interpretation of some of the terms used in the explanations above:

- **Adjacent:** A form is considered to be adjacent to the main surface if the form bears a LIES_NEAR relation to the main surface, where the relation's **distance** attribute is 0.
- **Intersects:** One GCD intersects another if one bears an INTERSECTS relation to the other.
- **Associated lance:** A form has an associated lance if the form is the smallest form that bears an INTERSECTS relation to the lance.
- **On:** A form is on the main surface if the form bears a LIES_ON relation to the main surface
- **Long flange:** A part is considered to have a long flange if its length is greater than a certain fraction of the part length. The fraction is given by the cost model variable **flangeLengthPercentage** (0.5 in starting point VPEs).
- **Shallow (in relation to part thickness):** A form is considered shallow in relation to part thickness if its depth is less than a certain fraction of the part thickness. The fraction is looked up by material type in the lookup table **tblMaterialThicknessFactor**.
- **Shallow (compared to aggregated form width):** To determine whether a form is shallow compared to aggregated form width, aPriori considers those EMBOSS or downward CURVED_BEND forms that intersect the primary form or are adjacent to the main surface. A form is considered shallow if its depth is less than a certain fraction of the aggregated width of those forms. (A part's forms are considered too shallow for Drawing to be performed on the part if the largest such form is less than that fraction of the aggregated form width.) The fraction is specified by the cost model variable **formDepthPercentage** (0.15 in starting point

VPEs). The post-forming width is estimated as the flattened forms' SER widths minus the forms' depths (the sum of the up and down depths).

User Inputs for Transfer Die

This section covers the following topics:

- Setup Options for Transfer Die
- Process Defaults and Thresholds for Transfer Die

Setup Options for Transfer Die

This section covers Transfer Die setup options. These are available from the process tree's top-level node.

The following options control the addition of extra space (for various purposes) around the flattened part:

- Width of Addendum Added to Blank Size [per side]: adds material for holding during stamping (or compensates for underestimation of flattened-part size).
- Edge Margin Width and Part Spacing Width: adds space for cutting a part without damaging adjacent parts

The following options control the layout and orientation of blanks during offline blanking:

- Evaluate Strip Nesting Layout: 1 Out
- Evaluate Strip Nesting Layout: 2 Out, Non-Interlocking, Mirrored
- Evaluate Strip Nesting Layout: 2 Out, Non-Interlocking, Rotated
- Evaluate Strip Nesting Layout: 2 Out, Interlocking, Mirrored
- Evaluate Strip Nesting Layout: 2 Out, Rotated, Interlocking
- Blank XY Orientation within Part Strip

The following options each control both extra space and blank orientation during offline blanking:

- Blank Pitch
- Coil Width

The following options constrain stock width; parts fail to cost if they require stock that doesn't meet these constraints:

- Maximum Strip Width
- Minimum Strip Width

The following options control the layout and orientation of blanks in the transfer press:

- Number of Concurrent Parts in Transfer Press
- Determine Transfer Pitch Based on:
- Blank XY Orientation within the Transfer Press

The following options affect operation assignment:

- Enable SCORING Operations for Bends
- Direct Trim Angle Threshold
- Enable In Die TAPPING operations

- Enable COINING Operations for SimpleHoles
- Enable SHAVING Operations for SimpleHoles

The following options control whether the sale of scrap should be assumed in material cost calculations:

- Enable Scrap Material Credit
- Enable Scrap Part Credit

A number of additional options are also provided—see below.

Evaluate Strip Nesting Layout: 1 Out

By default aPriori evaluates the cost of performing Offline Blanking with a 1-out layout only. You can override the default, and tell aPriori to evaluate the cost of other layouts as well by selecting **Yes** for one or more of the Evaluate Strip Nesting Layout... setup options. aPriori will choose the lowest-cost layout.

If you do not want a 1-out layout to be considered, select **No** for this setup option.

If you are using Rectangular Nesting (see [Material Utilization and Part Nesting for Transfer Die](#)), and you select **Yes** for this option, all Evaluate Strip Nesting Layout: 2 Out... setup options must be set to **No** (or the part will fail to cost).

Evaluate Strip Nesting Layout: 2 Out, Non-Interlocking, Mirrored

By default aPriori evaluates the cost of performing Offline Blanking with a 1-out layout only. You can override the default, and tell aPriori to evaluate the cost of other layouts as well by selecting **Yes** for one or more of the Evaluate Strip Nesting Layout... setup options. aPriori will choose the lowest-cost layout.

Select **Yes** for this setup option to include evaluation of a 2-out, non-interlocking, mirrored layout. See [Interlocking and Non-interlocking Layouts](#).

If you are using Rectangular Nesting (see [Material Utilization and Part Nesting for Transfer Die](#)), and you select **Yes** for this option, Evaluate Strip Nesting Layout: 1 Out must be set to **No** (or the part will fail to cost).

Evaluate Strip Nesting Layout: 2 Out, Non-Interlocking, Rotated

By default aPriori evaluates the cost of performing Offline Blanking with a 1-out layout only. You can override the default, and tell aPriori to evaluate the cost of other layouts as well by selecting **Yes** for one or more of the Evaluate Strip Nesting Layout... setup options. aPriori will choose the lowest-cost layout.

Select **Yes** for this setup option to include evaluation of a 2-out, non-interlocking, rotated layout. See [Interlocking and Non-interlocking Layouts](#).

If you are using Rectangular Nesting (see [Material Utilization and Part Nesting for Transfer Die](#)), and you select **Yes** for this option, Evaluate Strip Nesting Layout: 1 Out must be set to **No** (or the part will fail to cost).

Evaluate Strip Nesting Layout: 2 Out, Interlocking, Mirrored

By default aPriori evaluates the cost of performing Offline Blanking with a 1-out layout only. You can override the default, and tell aPriori to evaluate the cost of other layouts as well by selecting **Yes** for one or more of the Evaluate Strip Nesting Layout... setup options. aPriori will choose the lowest-cost layout.

Select **Yes** for this setup option to include evaluation of a 2-out, interlocking, mirrored layout. See [Interlocking and Non-interlocking Layouts](#).

If you are using Rectangular Nesting (see [Material Utilization and Part Nesting for Transfer Die](#)), and you select **Yes** for this option, Evaluate Strip Nesting Layout: 1 Out must be set to **No** (or the part will fail to cost).

Evaluate Strip Nesting Layout: 2 Out, Rotated, Interlocking

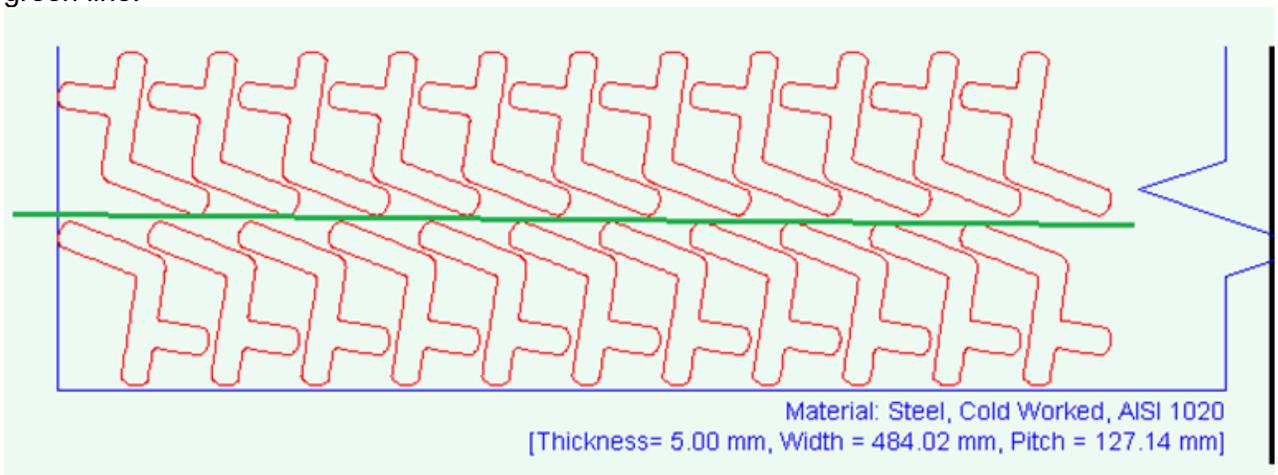
By default aPriori evaluates the cost of performing Offline Blanking with a 1-out layout only. You can override the default, and tell aPriori to evaluate the cost of other layouts as well by selecting **Yes** for one or more of the Evaluate Strip Nesting Layout... setup options. aPriori will choose the lowest-cost layout.

Select **Yes** for this setup option to include evaluation of a 2-out, interlocking, rotated layout. See [Interlocking and Non-interlocking Layouts](#).

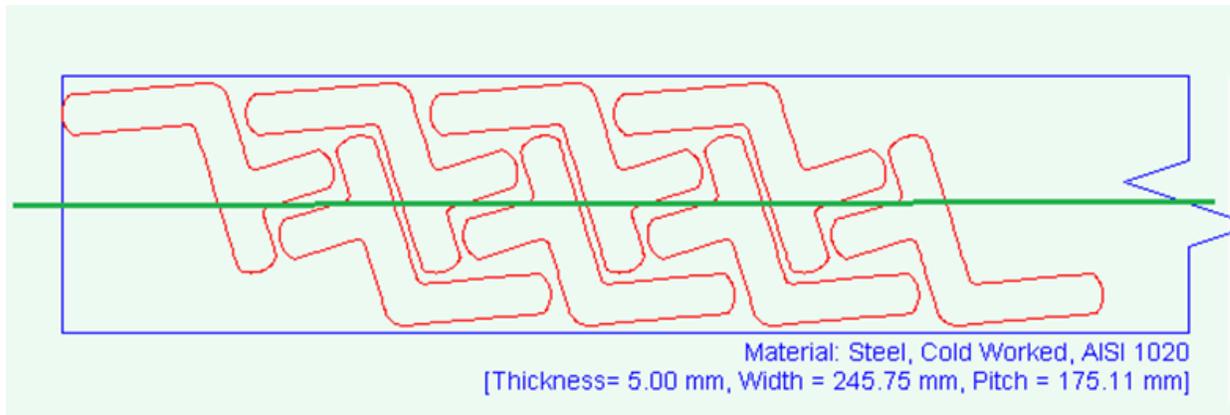
If you are using Rectangular Nesting (see [Material Utilization and Part Nesting for Transfer Die](#)), and you select **Yes** for this option, Evaluate Strip Nesting Layout: 1 Out must be set to **No** (or the part will fail to cost).

Interlocking and Non-interlocking Layouts

Double-row blank layouts can be either interlocking or non-interlocking. With non-interlocking layouts, the rows do *not* overlap in the width direction, that is, there is a line along the coil pitch direction such that one row is entirely above the line and the other row is entirely below the line. The image below shows a rotated, non-Interlocking layout; the top row is entirely above the green line, and the bottom row is entirely below the green line:



With interlocking layouts, the rows can overlap in the coil width direction. The image below shows a rotated, interlocking layout; there is no line in the pitch direction such that the top row is entirely above the line and the bottom row is entirely below the line:



Blank XY Orientation within Part Strip

With true-part nesting (see [Material Utilization and Part Nesting for Transfer Die](#)), specifies how aPriori will determine the blank's angle within the part strip. The first two options attempt to find the angle that optimizes material utilization; the third option allows the user to specify the angle explicitly. Select one of the following options:

- **Determine Angle optimizing utilization, using default increment:** specifies the part rotations aPriori considers in order to optimize nesting. aPriori considers non-negative, whole number multiples of **defaultIncrementAmount** that are less than 360 degrees. **defaultIncrementAmount** is a cost model variable that is set to 5 in aPriori starting point VPEs.
- **Determine Angle optimizing utilization, using specified increment:** specifies the part rotations aPriori considers in order to optimize nesting. aPriori considers non-negative, whole number multiples of this value that are less than 360 degrees. With a value smaller than the default, costing will be slower, but utilization might increase.
- **Specify Angle [0 = lengthWise, 90 = widthWise]:** specifies the part angle within the part strip.

Number of Concurrent Parts in Transfer Press

By default, aPriori's strip nesting calculations determine whether 1 or 2 parts are stamped at a time. You can specify the number of concurrent parts explicitly with this setup option. Select one of the following:

- 1
- 2

See also [Number of Concurrent Parts](#).

Determine Transfer Pitch Based on:

By default, in order to minimize transfer pitch, aPriori orients the blank in the transfer press so that the width of the SWER (smallest-width enclosing rectangle--see [Blank GCD](#)) is parallel to the transfer pitch direction.

You can override the default, and specify that aPriori should base the transfer pitch on the SER, or specify that aPriori should base the transfer pitch on the SWER only if SER and SWER differ significantly. Select one of the following:

- Blank SWER: always base transfer pitch on SWER, regardless of whether SWER and SER widths differ significantly. This is the default.
- Blank SER: always base transfer pitch on SER, regardless of whether SWER and SER widths differ significantly.
- Let aPriori Decide: base transfer pitch on SWER, assuming the SER and SWER differ significantly in width. If the SER and SWER don't differ significantly in width, base transfer pitch on SER. The SWER and SER widths are considered to differ significantly if the percentage difference between them is greater than the cost model variable **transferPitchSwerWidthThreshold** (1% in starting point VPEs).

See also [Blank XY Orientation](#).

Blank XY Orientation within the Transfer Press

By default, the blank is oriented in the transfer press so that the MainSurface's East direction is up (if the pitch direction is left-to-right). The MainSurface's East direction is listed in the Geometric Cost Drivers pane under the property **East Direction** (if transfer pitch is SER-based) or **SWER East Direction** (if transfer pitch is SWER-based)—see [Determine Transfer Pitch Based on:](#).

You can override the default, and align the MainSurface's East direction with a different direction within the transfer press. Select one of the following from the Transfer Press Blank Orientation dropdown list:

- right
- up
- left
- down

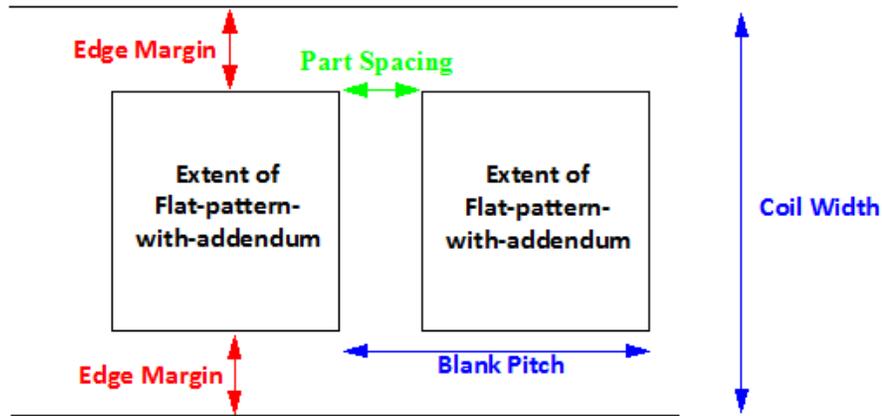
See also [Blank XY Orientation](#).

Blank Pitch

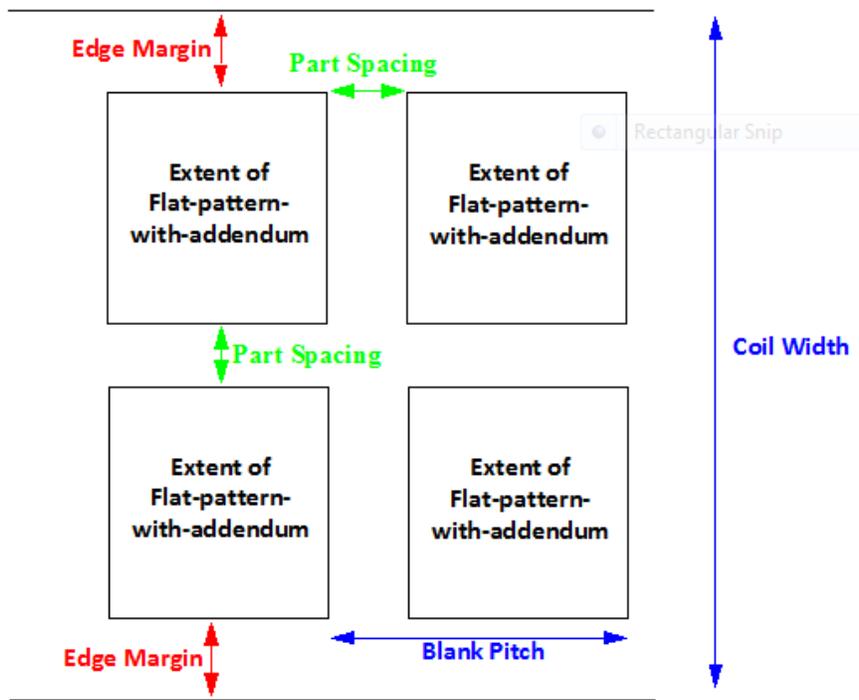
Blank pitch is the extent of the flat pattern (with addendum, if any) along the direction of coil flow for offline blanking, supplemented by the part spacing width. By default, this is calculated using aPriori's strip nesting algorithm. The default value is the sum of the following:

- Extent of the flat pattern (with addendum, if any) in the direction of coil flow, when best nested (as determined by the aPriori strip nesting algorithm)
- Part Spacing Width

1-Out Layout Edge Margins and Part Spacing



2-Out Layout Edge Margins and Part Spacing



You can override the default with this option, which affects both material utilization and tooling sizes and costs. It is your responsibility to ensure that the overrides have legal results, for example, that the resulting blanks do not overlap.

Select one of the following options:

- Default: calculated by aPriori (as described above)
- User Override: enter a value in millimeters or inches that is greater than or equal to 1.0 mm.

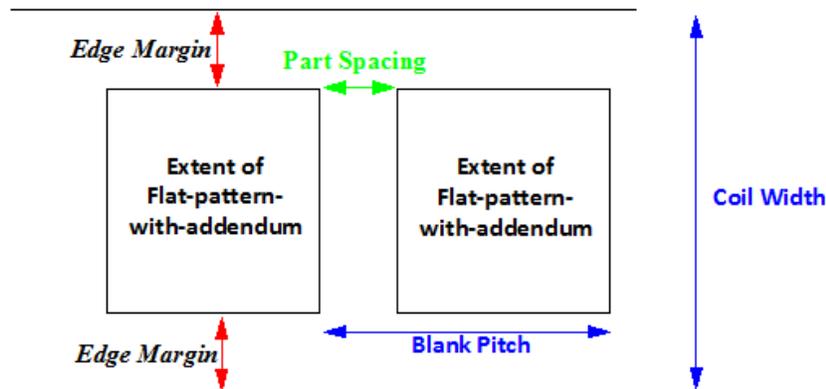
Coil Width

Coil width is determined by the extent of the flat pattern (with addendum, if any) in the direction perpendicular to the coil flow for offline blanking, supplemented by edge margins, as well as (for 2-out parts) part spacing width. By default, this is calculated using aPriori's strip nesting algorithm.

The default value for a 1-out layout is the sum of the following:

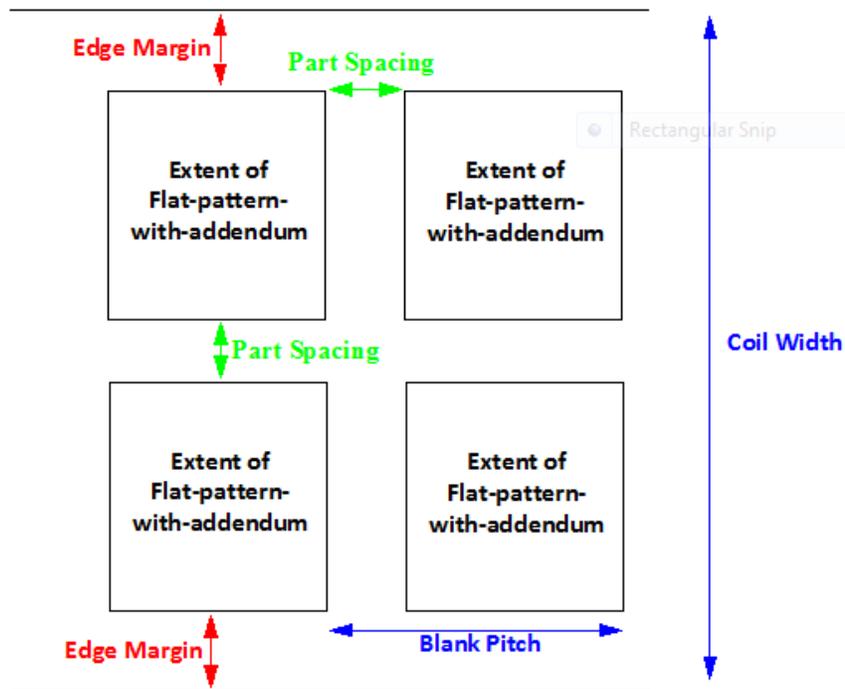
- Extent of the flat pattern (with addendum, if any) in the direction perpendicular to the coil flow, when best nested (as determined by the aPriori strip nesting algorithm)
- 2 * Edge Margin Width

1-Out Layout Edge Margins and Part Spacing



The default value for a 2-out layout is the sum of the following:

- 2 * Extent of the flat pattern (with addendum, if any) in the direction perpendicular to the coil flow, when best nested (as determined by the aPriori strip nesting algorithm)
- 2 * Edge Margin Width
- Part Spacing Width

2-Out Layout Edge Margins and Part Spacing

You can override the default with this option, which affects material utilization, as well as tooling sizes and costs. Note that coil width is constrained by the setup option [Minimum Strip Width](#).

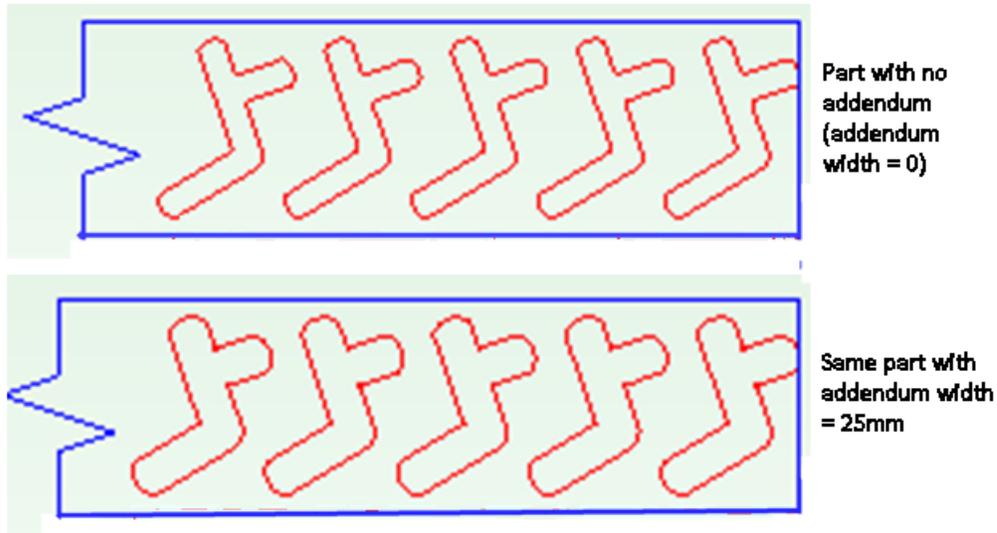
Select one of the following options:

- Default: calculated by aPriori (as described above)
- User Override: enter a value greater than or equal to 0.

Width of Addendum Added to Blank Size [per side]

An offset to be added all around the perimeter of the flattened part. You can enter a non-zero value in order to do one of the following:

- Add additional material for the purpose of holding the blank during the stamping process, which is subsequently trimmed away.
- Compensate for cases in which aPriori underestimates flattened blank size, for example, for highly deformed parts.

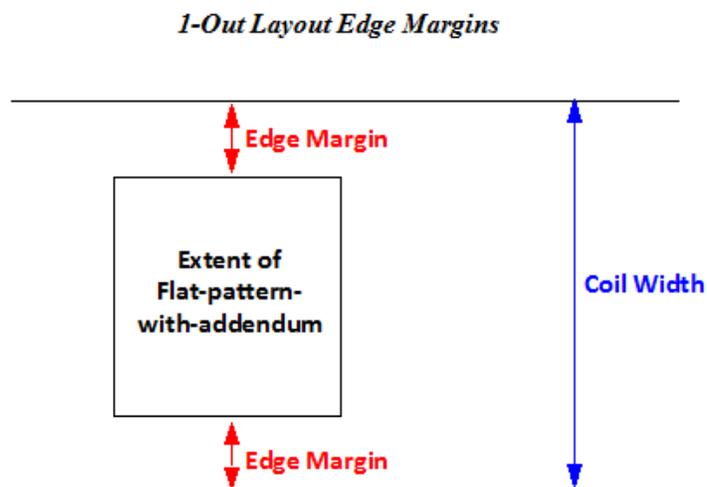


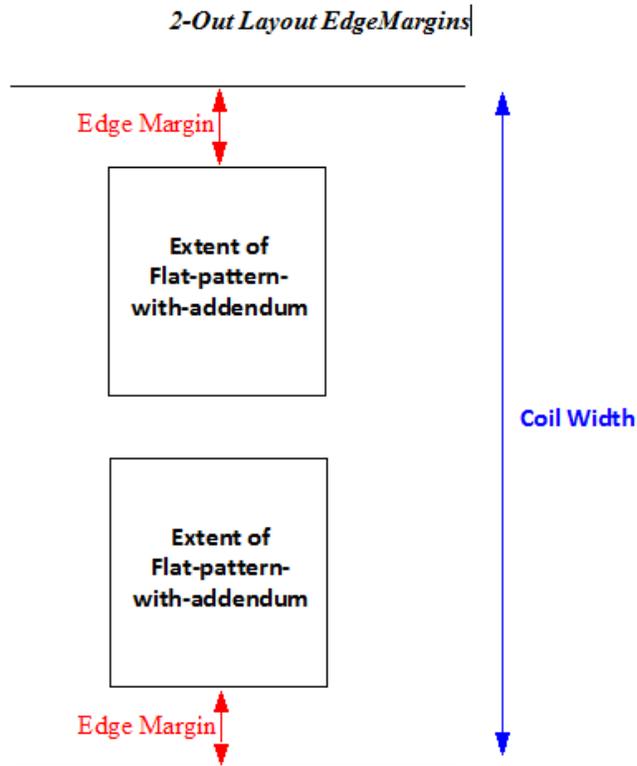
Select one of the following options:

- No Addendum: this is the default.
- Computed Based on Form Depth: derived from the lookup table **blankAddendumWidth**.
- User Override: enter a value greater than or equal to 0.

Edge Margin Width

This option specifies the width of the extra space between the coil edge and the flat pattern. In aPriori starting point VPEs, the default value is 1.5 times the material thickness. VPE administrators can customize the thickness multiplier with the cost model variable **defaultEdgeMarginWidthMultiplier**.





Select one of the following options:

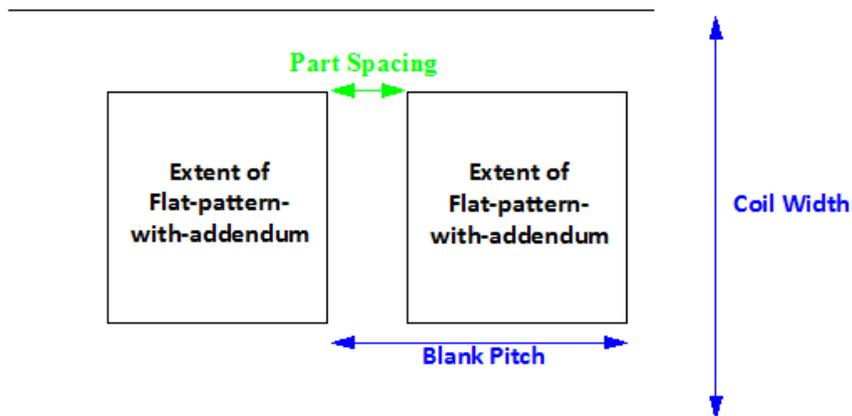
- Default: in aPriori starting point VPEs, the default value is 1.5 times the material thickness. VPE administrators can customize the thickness multiplier with the cost model variable **defaultEdgeMarginMultiplier**.
- User Override: enter a value greater than or equal to 0.

Part Spacing Width

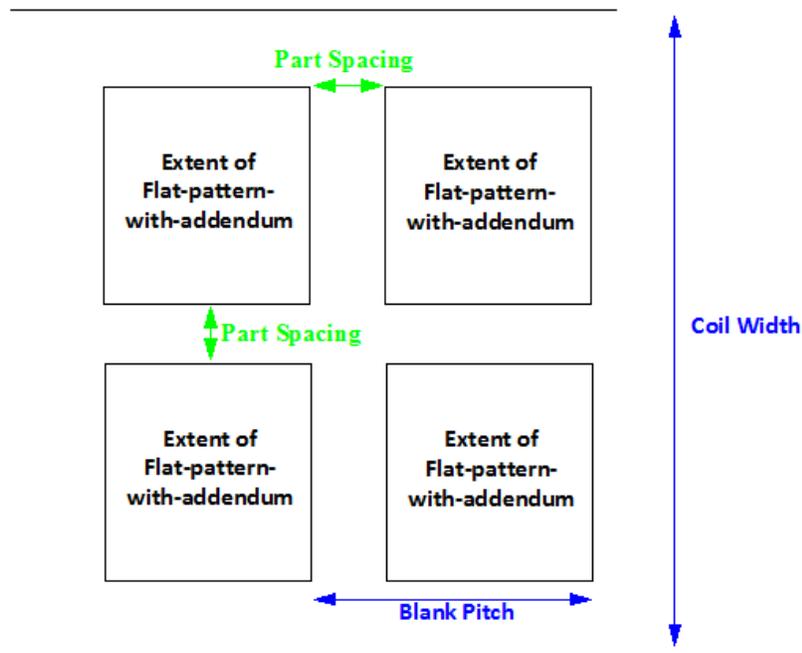
Width of extra space between adjacent blanks. This value specifies both the distance between blanks in the coil pitch direction, as well as the distance in the coil width direction between rows of a 2-out layout. In aPriori starting point VPEs, the default value is 1.5 times the material thickness. VPE administrators can customize the thickness

multiplier with the cost model variable **defaultPartSpacingWidthMultiplier**

1-Out Layout Part Spacing



2-Out Layout Part Spacing



Select one of the following options:

- Default: in aPriori starting point VPEs, the default value is 1.5 times the material thickness. VPE administrators can customize the thickness multiplier with the cost model variable **defaultPartSpacingMultiplier**.
- User Override: enter a value greater than or equal to 0.

Heat Treat of Die Components

Die components are heat treated by default. This option provides a dropdown list with the following items:

- Yes: perform heat treatment.
- No: do not perform heat treatment.

To override heat treatment, select **No** from the dropdown list.

Plating of Die Components

By default, the material used for die plating depends on the base tool material (see [Base Tool Material](#)). High-strength materials use the plating specified by the cost model variable **highStrengthMatlToolingCoatingType** (DuplexVariantic in starting point VPEs). Base material S7 uses Nitride plating. Base material D2 uses CVD plating. Any other base material uses the plating specified by the cost model variable **defaultToolingCoatingType** (Nitride in starting point VPEs).

High-strength material is defined as material with a tensile yield strength of 344.74 Mpa in starting point VPEs. VPE administrators can customize this threshold with the cost model variable **highStrengthMatlThreshold**.

To specify plating material explicitly, select one of the following options:

- None
- Nickel
- Chrome
- Nitride
- Teflon
- Tribo-Coating
- DuplexVariantic
- CVD

Base Tool Material

This is used to determine tool plating costs. By default, base tool material is S7. To specify base tool material explicitly, select one of the following options:

- D2
- A2
- S7

Stamp Assembly Qty

Select one of the following options:

- Default: specified by the cost model variable **defaultStampAssemblyQty**.
- User Override: enter a value greater than or equal to 0.

Number of 150, 300, 600, 800, 1000, 1200 Series Cam Units

Select one of the following options:

- Default
- User Override: enter a value greater than or equal to 0.

Freight Cost

Freight cost applied to tooling defaults to 0. To explicitly specify a tooling freight charge, enter a value greater than or equal to 0.

Total Carrying Cost

This is the cost for holding the completed tool in inventory prior to shipping. Total carrying cost applied to tooling defaults to 0. To explicitly specify a tooling carrying cost, enter a value greater than or equal to 0.

Total Gage Cost

Total gage cost applied to tooling defaults to 0. To explicitly specify a tooling gage cost, enter a value greater than or equal to 0.

Total Welding Cost

Total welding cost applied to tooling defaults to 0. To explicitly specify a tooling welding cost, enter a value greater than or equal to 0.

Maximum Strip Width

If aPriori calculates a required width (see [Coil Width](#)) that is greater than this value, the part fails to cost. In aPriori starting point VPEs, the maximum allowable strip width is 1828.8mm, by default. VPE administrators can customize the default with the cost model variable `maximumStripWidth`. You can override the default for the current part with this setup option. Select one of the following:

- Default
- User Override

Minimum Strip Width

This value constrains the choice of material stock. If aPriori calculates a required width (see [Coil Width](#)) that is less than this value, this value is used instead of the calculated value in order to determine material and tooling costs.

By default, the minimum allowable strip width is the calculated required strip width. You can override the default for the current part with this setup option. Select one of the following:

- Default
- User Override

Blank Cutting Method

Do not use this setup option with starting point VPEs. The starting point model assumes that blanking is done offline, on a separate machine. The VPE can be configured for inline blanking—please contact aPriori Support or your aPriori Account Manager. A future release will add out-of-the-box support for inline blanking.

Enable SCORING Operations for Bends

In aPriori Starting Point VPEs, bends are not scored by default. VPE administrators can customize the default with the cost model variable `defaultEnableScoringSetting`. You can override the default with this PSO. Select one of the following options:

- Default: specified by the cost model variable **defaultEnableScoringSetting** (No in aPiori Starting Point VPEs).
- User Override: select **Yes** or **No**.

Direct Trim Angle Threshold

- Do not use this setup option.

Enable In Die TAPPING operations

In aPiori starting point VPEs, in-die tapping is not enabled by default. VPE administrators can customize the default with the cost model variables **defaultEnableInDieTapping**. You can override the default with this PSO. Select one of the following options:

- Default: specified by the cost model variables **defaultEnableInDieTapping** (No in aPiori starting point VPEs).
- User Override: select either **Yes** or **No**.

Enable COINING Operations for SimpleHoles

In aPiori Starting Point VPEs, flanged, threaded holes are not coined, by default. VPE administrators can customize the default with the cost model variable **defaultEnableCoiningSetting**. You can override the default on a per-part basis with this PSO. Select one of the following options:

- Default: specified by the cost model variable **defaultEnableCoiningSetting** (No in aPiori Starting Point VPEs).
- User Override: select **Yes** or **No**.

Enable SHAVING Operations for SimpleHoles

In aPiori Starting Point VPEs, flanged, threaded holes are not shaved, by default. VPE administrators can customize the default with the cost model variable **defaultEnableShavingSetting**. You can override the default with this PSO. Select one of the following options:

- Default: specified by the cost model variable **defaultEnableShavingSetting** (No in aPiori starting point VPEs).
- User Override: select **Yes** or **No**.

High Strength Material Derate Percentage

This setup option can affect the number of occurrences of the Draw operation required to produce a given form. Use this to override the default behavior for parts that use high-strength material. Increasing this value can increase the number of draws.

The number of draws required for deep, primary forms or curved bends is calculated based on the form width reduction produced by each draw. The lookup table **drawReductionPercentage** lists the percentage of the pre-draw width that remains after a given draw (that is, initial draw, first subsequent draw, second subsequent draw, or third subsequent draw) for a given material thickness. For example, for the second subsequent draw of 1-inch-thick material, the table lists 81%. This means that the second subsequent draw (for 1-inch-thick material) results in a width that is 81% of the form's width immediately prior to that occurrence of the draw operation.

For high-strength materials, the percentage listed in the lookup table is itself increased by 10 percent, by default in starting point VPEs. For example, for the second subsequent draw of 1-inch-thick material, the table value of 81% is increased by 10 percent to 81.8%, for high-strength material. VPE administrators can customize the 10 percent default with the cost model variable **highStrengthMatlDeratePercent**. You can override the default on a per-part basis with this PSO.

High-strength material is defined as material with a tensile yield strength of 344.74 Mpa in starting point VPEs. VPE administrators can customize this threshold with the cost model variable **highStrengthMatlThreshold**.

Select one of the following options:

- Default: specified by the cost model variable **highStrengthMatlDeratePercent** (10% in aPriori starting point VPEs).
- User Override: enter a value between 0 and 100.

Part Height Allowance

This setup option specifies the difference between the part height and the height of the post component of the die. The default **Part Height Allowance** is specified by the cost model variable **partHeightAllowance** (12.7mm in starting point VPEs). Note that the post height is constrained by the value of **Minimum Part Height Plus Allowance**. That is, the post height is either the sum of the part height and **Part Height Allowance**, or the value specified by **Minimum Part Height Plus Allowance**, whichever is greater.

Post height affects die height. Die height (which affects tooling cost and machine selection) is the sum of the following:

- Product of post height and **Post Height Multiplier**
- Die allowance gap (specified by the cost model variable **dieAllowanceGap**—25.4mm in starting point VPEs)
- Lower die shoe height (selected from standard shoe sizes based on blank and addendum size, as well as on whether the part has a drawn primary form, in addition to)
- Upper die shoe height (selected from standard shoe sizes based on blank and addendum size, as well as on whether the part has a drawn primary form)

Select one of the following:

- Default: specified by the cost model variable **partHeightAllowance** (12.7mm in starting point VPEs)
- User Override: enter a value.

Minimum Part Height Plus Allowance

This setup option constrains the height of the die post. The post height is either the sum of part height and **Part Height Allowance**, or the value specified by this option, whichever is greater. Select one of the following:

- Default: specified by the cost model variable **minimumPartHeightPlusAllowance** (50.8mm in starting point VPEs)
- User Override: Enter a value greater than or equal to 0.

Post Height Multiplier

Specifies the number of posts that contribute to the die height. Die height, which affects tooling cost and machine selection, is the sum of the following:

- Product of post height (see [Part Height Allowance](#)) and Post Height Multiplier
- Die allowance gap (specified by the cost model variable **dieAllowanceGap**—25.4mm in starting point VPEs)
- Lower die shoe height (selected from standard shoe sizes based on blank and addendum size, as well as on whether the part has a drawn primary form, in addition to)
- Upper die shoe height (selected from standard shoe sizes based on blank and addendum size, as well as on whether the part has a drawn primary form)

Select one of the following:

- Default: specified by the cost model variable **postHeightMultiplier** (1 in starting point VPEs)
- User Override: enter a value greater than or equal to 1.

Enable Auto-Inclusion of IDLE Stations

By default, aPriori never includes IDLE stations in Transfer Die routings. With this setup option, you can enable the inclusion of die stations when aPriori deems them necessary.

With auto-inclusion enabled, aPriori may insert one or more IDLE stations to make room for cams. For example, an idle station may follow a cam trimming station if the trimmed edges require cams that are on the side of the part. Without auto-inclusion, aPriori assumes that the cams can be situated within the extent of the transfer pitch.

When an idle station is included, it compensates for the fact that a cam station's die shoe width (plus inter-die spacing) exceeds the transfer pitch. The idle station die shoe width (plus inter-die spacing) is the transfer pitch minus the extra width required for the cams. Transfer pitch is the blank pitch—see [Blank Pitch](#)—plus twice the value of the cost model variable **dieShoeWidthAllowance** (203.2mm in starting point VPEs), plus the value of the cost model variable **interDieSpacing** (25mm in starting point VPEs).

Idle stations have no associated operations, and so are not expandable/collapsible in the Process Manufacturing pane; they are recognizable by the absence of a plus sign, , or minus sign, .

 Die Station:4

Select one of the following options:

- Default: **No** (IDLE stations never included)
- User Override: select **Yes** or **No** from the dropdown list. (**Yes** enables auto-inclusion.)

Number of Shear Planes

By default in starting point VPEs, shear force is calculated on the assumption that cluster punching is *not* used (that is, on the assumption of a single shear plane, with all GCDs pressed at the same time). VPE administrators can customize the default number of shear planes with the cost model variable **numShearPlanes**. In addition, users can override the default on a per-part basis with this setup option.

Multiple shear planes indicate the use of cluster punching, with different groups of GCDs pressed in a staggered fashion, rather than simultaneously. Required press force decreases as the number of shear planes increases. A decrease in required press force can sometimes lower costs due to selection of a lower-overhead machine.

Enable Scrap Material Credit

By default in starting point VPEs, the cost model assumes that material scrap (such as trim scrap) is *not* sold for credit. Administrators can customize the default with the cost model variable **enableScrapMaterialCredit** (**false** in starting point VPEs). With this setup option, users can override the default on a per-part basis.

Enabling scrap material credit increases material utilization and decreases material cost. The credit rate is specified as a percentage of the material rate by the material property **Scrap Cost Percent**.

Enable Scrap Part Credit

By default in starting point VPEs, the cost model assumes that the material from scrapped parts is *not* sold for credit. Administrators can customize the default with the cost model variable **enableScrapPartCredit** (**false** in starting point VPEs). With this setup option, users can override the default on a per-part basis.

Enabling scrap part credit increases material utilization and decreases material cost. This includes credit for parts scrapped by this process as well as by downstream processes. The credit rate is specified as a percentage of the material rate by the material property **Scrap Cost Percent**.

Coating of Tooling

Default tool coating is **Nitrided Steel**. With this setup option, users can override the default on a per part basis, and choose from among the materials defined in the lookup table **tblToolCoating**.

Tooling Material

Default tool material is specified by the tool shop variable **Default Tool Material**. With this setup option, users can override the default on a per part basis, and choose from among the materials defined in the tool shop.

Process Defaults and Thresholds for Transfer Die

The table below lists some of the important cost model variables.

Follow these steps to access plant variables for a given VPE and process group:

- 1 Select **Tools > VPE Toolset**, and then click the **VPE Manager** button in the VPE Toolset window.
- 2 Double click the desired VPE in the Select VPE window.
- 3 In the VPE Manager, click + to expand the **Sheet Metal** process group.
- 4 Under **Sheet Metal—Transfer Die**, click **Variables**.

Variable Name	Link to Description
aerialCamAngleUpperThreshold	Cam Bundling for Transfer Die
defaultEdgeMarginWidthMultiplier	Edge Margin Width
defaultEnableCoiningSetting	Enable COINING Operations for SimpleHoles
defaultEnableInDieTapping	Enable In Die TAPPING operations
defaultEnableScoringSetting	Enable SCORING Operations for Bends
defaultEnableShavingSetting	Enable SHAVING Operations for SimpleHoles
defaultPositionToleranceEdgeSegment	Post-form Trimming
defaultGcdPositionTolerance	Post-emboss Piercing
defaultIncrementAmount	Blank XY Orientation within the Transfer Press
defaultStampAssemblyQty	Stamp Assembly Qty
defaultUtilizationMethod	Material Utilization and Part Nesting for Transfer Die
depthToMatlThicknessRestrikeThreshold	Restriking
dieAllowanceGap	Part Height Allowance
dieShoeLengthAllowance	Die Shoe Dimensions and Spacing
dieShoeWidthAllowance	Die Shoe Dimensions and Spacing
edgeTrimmingPositionToleranceThreshold	Post-form Trimming
enableMultiStationTrimming	Post-form Trimming
enableScrapMaterialCredit	Enable Scrap Material Credit
enableScrapPartCredit	Enable Scrap Part Credit
flangeLengthPercentage	Primary Forming for Transfer Die
formDepthPercentage	Primary Forming for Transfer Die
highStrengthMatlDeratePercent	High Strength Material Derate Percentage
highStrengthMatlThreshold	High Strength Material Derate Percentage
interDieSpacing	Die Shoe Dimensions and Spacing
matlYieldStrengthRestrikeThreshold	Restriking
maximumStripWidth	Maximum Strip Width
maxRamDirectionTangentAngle	Edge Trimming, Cam Piercing
maxScrapSizeThreshold	Post-form Trimming
minFormSurfaceToleranceRestrikeThreshold	Restriking
minOpenAngleEdgeTrimming	Edge Trimming
minimumPartHeightPlusAllowance	Minimum Part Height Plus Allowance

minimumStripWidth	Minimum Strip Width
minRadiusOfCurvatureRestrikeThresholdMultiplier	Restriking
partHeightAllowance	Part Height Allowance
postHeightMultiplier	Post Height Multiplier
transferPitchSwerWidthThreshold	Determine Transfer Pitch Based on:
widthToDepthRestrikeThreshold	Restriking

The site variables listed below are described in [Flattening for Transfer Die](#):

- **flatteningDirection**
- **flatteningFillHoleMethod**
- **flatteningInitialStrainValue**
- **flatteningSolverType**
- **flatteningSurface**
- **flatteningTimeoutSeconds**

15 Sheet Metal—Soft Tooled

The Sheet Metal process group lets you estimate manufacturing times and costs for a wide variety of sheet metal fabrication processes and subsequent machining operations. This chapter covers all processes that do not require hard tooling. For information on other sheet metal processes, see the chapters [Sheet Metal—Hard Tooled](#), [Sheet Metal--Hydroforming](#), [Sheet Metal—Transfer Die](#), and [Sheet Metal—Stretch Forming](#).

The chapter includes the following sections:

- Cost Model Overview
 - GCD Extraction
 - Feasibility and Routing
 - Cost Algorithms and Calculations
 - User Inputs
 - Process Defaults and Thresholds
 - Design-to-cost Configuration for Sheet Metal
-

Cost Model Overview

This overview section summarizes assumptions and limitations of the following aspects of the model:

- General Process
- Part Geometry

Materials and Stock Forms

- Machines
- Tooling

General Process

The model supports various routings involving for the following types of processes:

- 3D Laser
- Cut To Length
- Deslag
- Bend Brake
- Roll Bending
- Laser Cut
- Laser Punch and Plasma Punch
- OxyFuel Cut
- Plasma Cut
- Shear
- Turret Press
- Waterjet Cut

Cut To Length is a blade cutting process that cuts rolls of sheet metal to a given length. Cut-to-length lines unroll the sheet, level it, and cut to the desired length. Generally cut-to-length lines can handle stock 5mm or less in thickness.

Shear is a blade cutting process that supports straight edge cuts from sheet stock. Shears can be hydraulically powered, human powered, or use an electromechanical mechanism.

Deslag is modeled in aPriori as a manual process to remove slag after oxy-fuel or plasma operations, and is completed by a handheld grinder. Slag consists of by-products (mostly metal oxides and silicon dioxide) of the separation of the metal from its raw ore. Note that deburring is also available from secondary machining (Automated Deburr and Manual Deburr). Burs, in contrast to slag, are irregularities in the metal that result from cutting processes.

Bend Brake is a sheet metal process used after cutting to create straight or simple curved bends. Bend-brakes can be hand operated or driven (hydraulically or mechanically). This operation cannot form bend radii less than the thickness of the material.

Laser Cut is a flame cutting process typically used on thin sheet metal (up to 25.4mm thickness). A laser operates on a CNC basis--cutting parts based on an input file. This operation is very slow when cutting thick material, and may require a secondary operation such as deslag or shot blast. Laser machines are generally large, as they can handle large stock sheets (at least 4' x 8') of metal.

OxyFuel Cut is a flame cutting process typically used on thick sheet metal (up to 305mm thickness). It can be performed manually or as a CNC operation. CNC operations can have up to ten torches running in parallel. This operation is too powerful to cut thin material (since it causes part deformation), cannot achieve tight tolerances, and requires a secondary operation such as deslag or shot blast to clean up the cuts. CNC oxy-fuel cut machines are generally large, as they can handle large stock sheets (at least 4' x 8') of metal..

Plasma Cut is a flame cutting process typically used on medium thickness sheet metal (up to 77mm thickness) It can be performed manually or by CNC machines. aPriori only supports CNC machines. CNC machines can have two plasma heads running in parallel. This operation cannot achieve tight tolerances, and requires a secondary operation such as deslag or shot blast to clean up the cuts. CNC Plasma machines are generally large, as they can handle large stock sheets (at least 4' x 8') of metal.

Turret Press is a punching process that supports periphery cutting and hole making for thin (< 10mm) sheet metal. This operation is very slow when cutting thick material, and may require a secondary operation such as deslag, or a machining deburring process (Automated Deburr or Manual Deburr), or shot blast to clean up the cuts. Turret presses are CNC controlled and can be driven mechanically, hydraulically, or with a combination of both. Turret machines are generally large, as they can handle large stock sheets (at least 4' x 8') of metal.

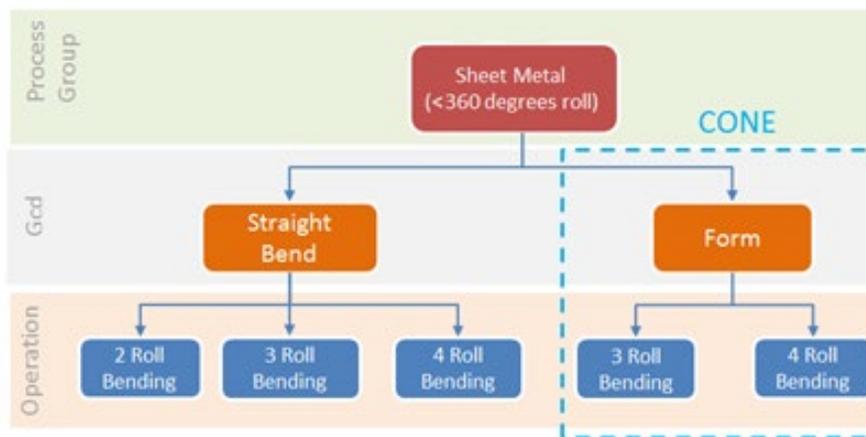
Laser Punch and **Plasma Punch** are hybrid processes for combination machines which include both a turret press and either a laser or a plasma cutting head. The advantage of these processes is that parts with holes and complex shapes can have both operations completed without changing machines. Accuracy can also be enhanced as it is possible for alignment errors to be introduced when parts are moved between two different machines. Because these are combination machines, the individual cost factors for laser cutting, plasma cutting, and turret press punch are generally the same as for the individual processes.

Waterjet Cut is capable of cutting a wide variety of materials using a very high-pressure jet of water, or a mixture of water and an abrasive substance. The cutter is commonly connected to a high-pressure water pump where the water is then ejected from the nozzle, cutting through the material by spraying it with the jet of high-speed water. Additives in the form of suspended grit or other abrasives such as garnet can assist in this process. Although Waterjet Cut may result in higher costs when compared to Laser Cut or Plasma Cut, Waterjet may be preferred when the materials being cut are sensitive to the high temperatures generated by other methods. Waterjet Cut does not create a "heat-affected zone" (HAZ), so Waterjet Cut allows metals to be cut without harming or changing their intrinsic properties. **Note:** Because Waterjet Cut tends to be more expensive than other processes, aPriori typically does not automatically choose it. You should select it manually if you feel that the benefits listed above are worthwhile in your situation.

Roll Bending handles bend diameters that are too large for Bend Brake. The Sheet Metal roll bending process is similar to the process available for Bar & Tube (see Bar & Tube Fabrication Process Group on page 171) except that Sheet Metal:

- handles only non-360 degree tubes
- does not support laser tube welding and re-rolling
- can automatically select roll bending machines (Bar & Tube Fab must have manual machine selection)
- can handle conical bends

For Roll Bending to be selected, the component must have at least one straight bend.



Three rolling processes are available:

- 2 roll bending
- 3 roll bending with initial pinch
- 4 roll bending with double pinch

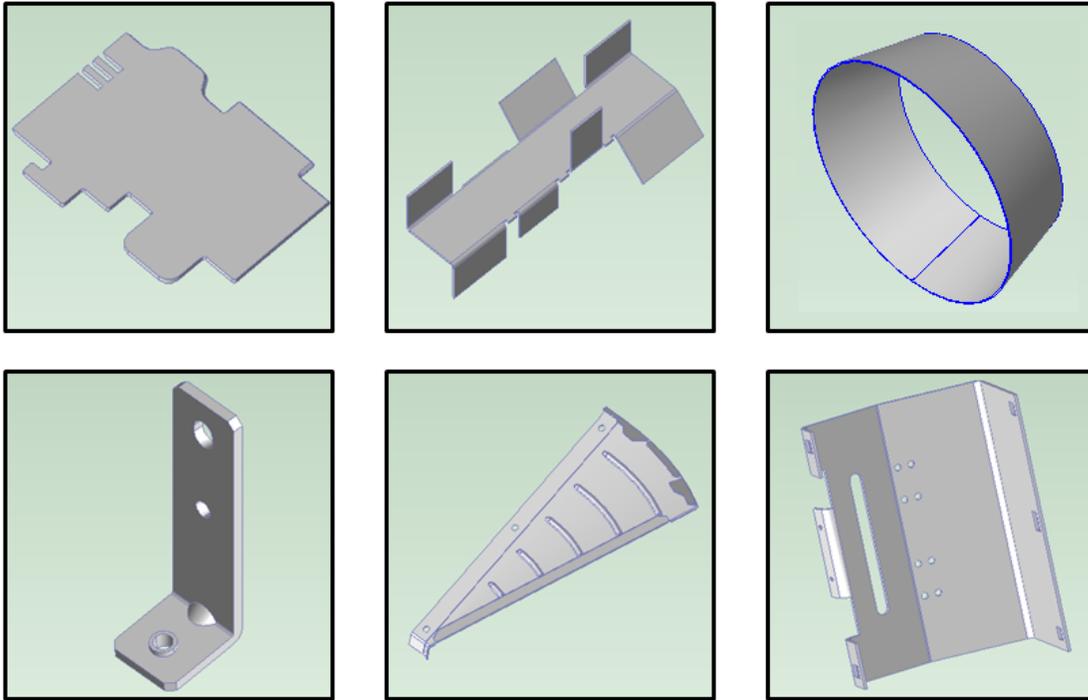
Conical bends are supported by 3- and 4-roll bending.

If you have licensed the appropriate modules, your routing can include optional machining, turning, heat treatment, surface treatment, and packaging processes.

See [Process-level Routing](#) and [Process-level Feasibility](#) for more information.

Part Geometry

A small selection of example parts is shown below.

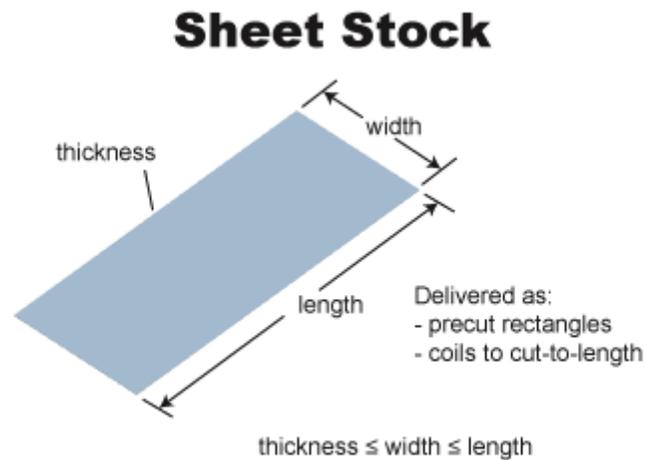


In addition to solid CAD models, the Sheet Metal process group supports surface CAD models, which represent surfaces only, rather than solid geometry. See [Surface-only CAD Models for Sheet Metal](#).

See [GCD Extraction](#) for more information.

Materials and Stock Forms

Standard sheet thicknesses vary depending on the material selected. Aluminum, for example, ranges from 0.45 mm in thickness to 6.35 mm, while steel ranges from 2 mm to 160 mm. Widths are available in 4 ft. or 5 ft. Lengths are available in 8 ft. or 10 ft.



Materials Include the following:

- Aluminum: 3003, 5052, 6061
- Copper: 110
- Galvanized Steel: HR-1010, HR-1012, HR-1020
- Stainless Steel: 304, 316, 316L
- Steel: CR-1010, CR-1012, CR-1020, HR-1010, HR-1012, HR-1020

Material composition details include the following:

- Unit Cost (USD / kg)
- Density (kg / m³)
- Shear Strength (MPa)
- Ultimate Tensile Strength (MPa)

Material details include equivalent DIN and EN name standards for use with regional VPEs.

Material stock details include the following:

- Thickness (mm)
- Width (mm)
- Length (mm)
- Unit Cost (USD / kg)

See [Material Selection](#) for more information.

Machines

The following tables list important machine property value ranges. Ranges are listed below for those processes that support a choice of machines:

3D Laser

Property	Low End	High End
Power (Watts)	2,000.0	5,000.0
Rapid Traverse Rate (mm / min)	20,000.0	60,000.0

Bed Length (mm)	1,300.0	4,300.0
Bed Width (mm)	1,300.0	2,800.0
Bed Height (mm)	600.0	800.0

Cut-to-Length

Property	Low End	High End
Roll Width (mm)	1,219.0	2,438.0

Shear

Property	Low End	High End
Shear Speed	11.0	132.0
Shear Length (mm)	2,438.0	3,100.0

Bend Brake

Property	Low End	High End
Max Bend Length (mm)	415.0	4,267.2
Max Sheet Width (mm)	510.0	3,810.0
Press Force (kN)	75.0	2,373.0

Laser Cut

Property	Low End	High End
Bed Length (mm)	1,524.0	6,096.0
Bed Width (mm)	3,048.0	4,876.0
Power (watts)	2,000	6,000
Rapid Traverse Rate (mm/min)	60,000	154,000

OxyFuel Cut

Property	Low End	High End
Bed Length (mm)	1,524.0	6,096.0
Bed Width (mm)	1,219.0	3,048.0
Number of Heads	1	6
Rapid Traverse Rate (mm/min)	12,700	127,000

Plasma Cut

Property	Low End	High End
Bed Length (mm)	1,250.0	7,315.2
Bed Width (mm)	1,219.0	3,225.8
Number of Heads	1	4
Power (watts)	100	1,000
Rapid Traverse Rate (mm/min)	9,000	30,480

Turret Press

Property	Low End	High End
Nibble Rate (cycles / min)	420.0	600.0
Punch Rate (cycles / min)	240.0	280.0
Max Sheet Length (mm)	1,260.0	4,978.0
Max Sheet Width (mm)	650.0	1,524.0
Max Punch Size (mm)	88.9	114.3
Press Force (kN)	215.8	490.3

Laser Punch

Property	Low End	High End
----------	---------	----------

Max Sheet Length (mm)	2500.00	5000.00
Max Sheet Width (mm)	1250.00	1550.00
Max Sheet Thickness (mm)	6.00	8.00
Power (watts)	2,000	4,000
Punch Rate (cycles / min)	315	1,200
Rapid Traverse Rate (mm/min)	81,280	125,000
Press Force (kN)	220	328.81

Plasma Punch

Property	Low End	High End
Max Sheet Length (mm)	2000.00	6000.00
Max Sheet Width (mm)	1270.00	2500.00
Max Sheet Thickness (mm)	6.35	25.00
Power (watts)	100	400
Punch Rate (cycles / min)	125	600
Rapid Traverse Rate (mm/min)	25,000	70,000
Press Force (kN)	298.92	1,000

2-Roll Bending

Property	Low End	High End
Roll Working Length (mm)	200.00	2050.00
Steel Thickness (mm)	1.5	5.0
Top Roll Diameter (mm)	88.90	420.00

3-Roll Bending

Property	Low End	High End
Roll Working Length (mm)	1500.00	3100.00
Top Roll Diameter (mm)	130.00	381.00
Weight (kg)	1025.00	7650.00
Min Multi Pass Diameter (mm)	333.2	1103.20
Max Multi Pass Thickness (mm)	2.00	19.05
Min Single Pass diameter (mm)	169.00	900.00
Max Single Pass Thickness (mm)	1.50	15.00

4-Roll Bending

Property	Low End	High End
Roll Working Length (mm)	2000.00	4089.00
Top Roll Diameter (mm)	152.40	730.00
Weight (kg)	2315.00	68000.00
Min Multi Pass Diameter (mm)	363.2	1614.00
Max Multi Pass Thickness (mm)	4.00	75.00
Min Single Pass diameter (mm)	224.00	1242.00
Max Single Pass Thickness (mm)	3.00	65.00

Waterjet Cut

Property	Low End	High End
Bed Length (mm)	660.0	13,995.4
Bed Width (mm)	373.0	5,992.0
Rapid Traverse Rate (mm/min)	4,572.00	38,100.0
Mixing Tube Diameter (mm)	0.762	1.061
Abrasive Flow Rate (kg/min)	0.34	0.46

See [Machine Selection](#) for more information.

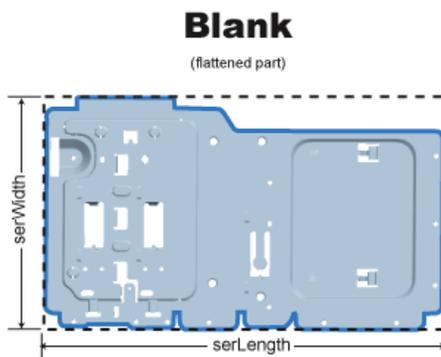
Tooling

No hard tooling is required for the processes covered in this chapter.

GCD Extraction

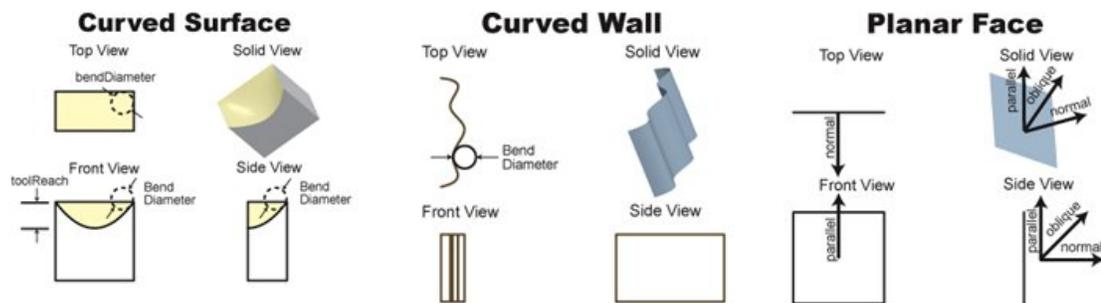
aPriori extracts the geometry of a CAD model in the form of geometric cost drivers (GCDs) that include surfaces and holes, as well as bending and forming GCDs, lances, and a GCD that represents the flattened blank from which the sheet metal part is formed. As usual, there is a special GCD, **Component**, that represents the part as a whole. Below are some of the important properties of each of these GCD types. Each GCD's units are shown in metric.

- **Component:**
 - Volume (mm³)
 - Surface Area (mm²)
 - Length, Width, and Height (millimeters)
 - Number of Surfaces
 - Min Thickness, Max Thickness, and Avg Thickness (millimeters)
 - Length Direction, Width Direction, and Height Direction: each of these is a unit vector, two of whose components are 0 (the other component is 1 or -1). These vectors can be compared with the Direction vector of another GCD (such as a Setup Axis) in order to determine whether the GCD's direction is aligned with the part's length, width, or height.
- **Blank:**
 - Perimeter (millimeters)
 - SER Length and SER Width (smallest enclosing rectangle dimensions in millimeters)
 - Thickness (millimeters)
 - Straight Length (millimeters)



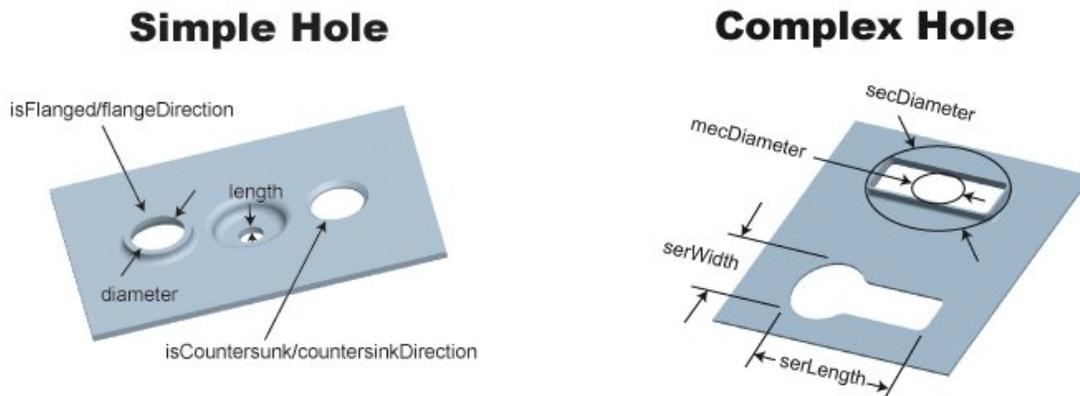
- **Surfaces (Curved Surface, Curved Wall, and Planar Face):**
 - Finished Area (mm²)
 - Bend Diameter (millimeters)
 - Perimeter (millimeters)

- SER Length and SER Width (smallest enclosing rectangle dimensions in millimeters)
- Corner Diameter (millimeters)
- Inside Diameter (millimeters)
- Number of Surfaces
- Fillet Min Angle and Fillet Max Angle (degrees)
- Round Radius (millimeters)
- Round Length (millimeters)
- Wall Corner Diameter (millimeters)



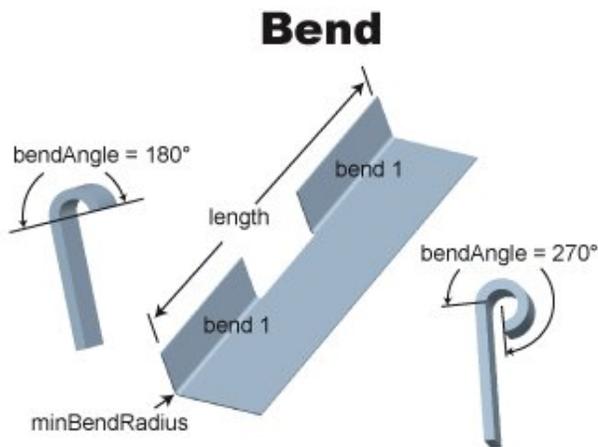
■ Holes (Simple Hole, Complex Hole):

- Diameter (millimeters),
- Length and Depth (millimeters)
- Volume (mm^3)
- Surface Area (mm^2)
- Hole type (THROUGH or BLIND)
- Blind, Sleeve Pin, Threaded, Countersunk, and Flanged (TRUE or FALSE)

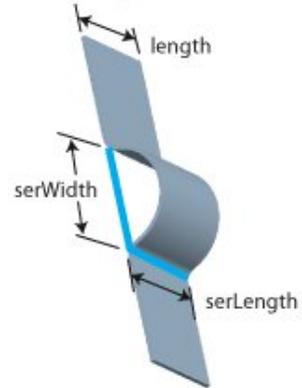


■ Bending/Forming (Bend, Multi Bend, Form, Shear-Form):

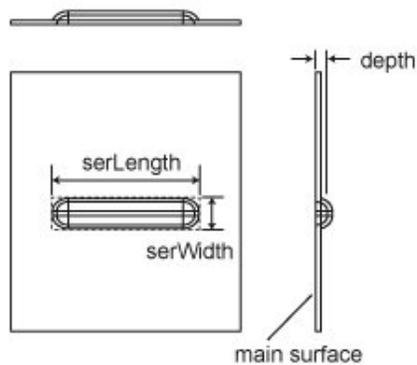
- Bend Angle (degrees)
- Length (millimeters)
- Bend Flap Size (millimeters)
- Min Bend Radius (millimeters)
- SER Length (millimeters)
- SER Width (millimeters)
- Perimeter (millimeters)



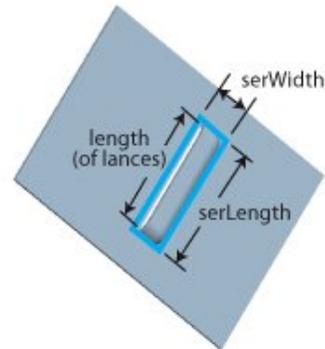
Multiple Bend



Form



Shear-Form



- **Lance:**
 - Length (millimeters)
- **Edge:**
 - Edge Type (Sharp or Chamfer)
 - Is Accessible
 - Is Staright
 - Length
 - Height
 - Angle
 - Round Radius
 - Min Concave Radius

- Min Convex Radius
- Min Wall Angle
- Max Wall Angle
- Internal

You can modify Form GCDs by adding or removing surfaces, and you can define a new Form GCD by the specifying the included surfaces—see [Creating and Editing Forms](#).

In addition to solid CAD models, the Sheet Metal process group supports surface CAD models, which represent surfaces only, rather than solid geometry. See [Surface-only CAD Models for Sheet Metal](#).

Feasibility and Routing

When you choose the Sheet Metal process group, aPriori selects process-level routings, operation-level routings, as well as machines and materials. These procedures are described in the following sections:

- [Process-level Routing](#)
- [Process-level Feasibility](#)
- [Material Selection](#)
- [Machine Selection](#)
- [Operation-level Feasibility and Routing](#)

Process-level Routing

This section covers available routings for soft-tooled processes. Production volume is generally the primary consideration that should guide your choice between soft tooling and hard tooling processes. Soft tooling processes have longer cycle times, but there is no upfront tooling investment required. Hard tooling requires an upfront investment (which can be significant), but the cycle times are generally very fast, even for complex sheet metal parts.

Another consideration that should guide you in your choice between hard and soft tooling processes is part thickness. Generally, hard tooling processes can only handle fairly thin sheet metal. Plate stock (> 1/4 inch) requires soft-tooled processes such as Plasma or OxyFuel cutting.

If the Machining process group has been licensed, routings may include 3-Axis Milling, Cylindrical Grinding, Gun Drill, and 2-axis Wire EDM operations, and (if helical groove geometry is present) Single Index Milling and Rotor Grinding operations. If the optional Turning module also has been licensed, routings also can include turning processes (2-axis and 3-axis lathes).

The routing also includes subsequent optional Heat Treatment, Surface Treatment, Part Assembly, as well as packaging, testing, and inspection processes, if your company has licensed these modules.

Following are the available soft-tooled sheet metal routings:

- **[CTL]/Laser/[Bend]:** [CTL] > Laser Cut > [Bend Brake] > [Roll Bending]
- **[CTL]/Laser Punch/[Bend]:** [CTL] > Laser Punch > [Bend Brake] > [Roll Bending]

- **[CTL]/ Plasma /[Deslag]/[Bend]:** [CTL] > Plasma Cut > [Deslag] > [Bend Brake] > [Roll Bending]
- **[CTL]/ Plasma Punch/[Deslag]/[Bend]:** [CTL] > Plasma Cut > [Deslag] > [Bend Brake] > [Roll Bending]
- **[CTL]/ OxyFuel /[Deslag]/[Bend]:** [CTL] > OxyFuel Cut > [Deslag] > [Bend Brake] > [Roll Bending]
- **[CTL]/ Waterjet /[Bend]:** [CTL] > Waterjet Cut > [Bend Brake] > [Roll Bending]
- **[CTL]/ Turret /[Bend]:** [CTL] > Turret Press > [Bend Brake] > [Roll Bending]
- **[CTL]/[Bend]:** [CTL] > [Bend Brake] > [Roll Bending]

In addition, the following routings, although they include hard-tooled processes, include the **3D Laser** and **Shear** processes, which are themselves soft tooled.

- **Prog Die:** Progressive Die > [Stage Tooling] > [3D Laser]
- **Transfer Die:** Transfer Press* > [3D Laser]
- **[CTL]/Shear/Press:** [CTL] > [Shear] > Std Press
- **[CTL]/Shear:** [CTL] > [Shear] > [Roll Bending]

Every routing has a special initial process, **Material Stock**, that serves as the locus of material cost and utilization calculations (see [Material Cost and Utilization](#)).

If you have licensed the Machining process group, your routing can include any of the following secondary processes:

- 3 Axis Mill
- Drill Press
- Wire EDM
- Grinding
- Automated Deburring
- Manual Deburring

Your routing can also include the following subsequent optional processes, if you have licensed these modules:

- Heat Treatment
- Surface Treatment
- Part Assembly
- Other Secondary Processes (packaging, testing, and inspection processes)

[CTL]/Shear routings can include secondary Chemical Milling—see [Chemical Milling](#).

Process-level Feasibility

The **Laser Cut**, **Laser Punch**, **OxyFuel Cut**, **Plasma Cut**, **Plasma Punch**, and **Waterjet** processes have these feasibility requirements:

- Part has no flanged holes.
- Part has blind holes.

- Part has no forms.

The **OxyFuel Cut** and **Waterjet Cut** processes have these additional feasibility requirements:

- Part has no countersunk holes.
- Part has no threaded holes.

The **Waterjet Cut** process has these additional feasibility requirements:

- Part has no chamfered holes.
- For simple holes, the hole diameter must be more than kerf width (see *A note about kerfs on page 1024*). For complex holes, the minimum hole width or length must be more than kerf width.
- The ratio of wall thickness to part thickness must exceed 0.003 mm.

For the following processes, if tolerance or roughness are not within Process Tolerance Capability, aPriori adds a machining process to the routing:

- **Turret Press, Generic Press, Std Press, Tandem Press, Transfer Press**
- **Progressive Die**
- **Laser Cut, Oxy Fuel Cut, Plasma Cut, Waterjet Cut**
- **Laser Punch, Plasma Punch**
- **3D Laser**
- For **Material Stock**, aPriori checks the requested GTOLs on As Supplied surfaces to determine if subsequent machining is required.

Note that in some cases this can result in inflated costs, because when machining is required to obtain the required tolerance, the actual manufacturing process will use machining to create the hole, rather than using one of the above processes followed by machining.

The **Roll Bending** process has the following limitation: 360 degree bending is not supported.

See also [Chemical Milling](#).

Material Selection

In direct integration mode with Pro/ENGINEER, if the composition selection mode is **MCAD**, aPriori selects the MCAD composition from the part, if available. Otherwise aPriori selects the VPE default material (Steel, CR-1020).

In CAD-independent mode, aPriori selects the VPE default material (Steel, CR-1020).

In both direct integration and CAD-independent mode, you can use aPriori's selection or else manually select a material composition and override the material unit cost. To manually specify a material, select **Edit > Material Selection** in the Manufacturing Process pane (see also [Selecting material in Manufacturing Process Information](#)). You can override the unit cost if desired.

Note: If you change the selected material for a part, the part's CAD file must be accessible to aPriori so that it can recalculate the flattened part outline.

Material Stock can be selected from a list of common stock sizes or from virtual stock. Actual stock can be automatically or manually selected. Material cost is based on the cost per kilogram of a material as indicated in the **Material Selection** dialog. If a stock size is available and selected, the cost per kilogram will reflect the stock's material rate.

If a part's dimensions do not match an available material stock, aPriori creates virtual stock. The virtual stock is either a 4 foot by 8 foot sheet of stock or, if the smallest enclosing rectangle of the part is larger than 4 feet by 8 feet, a sheet is the size of the smallest enclosing rectangle.

The user can override the unit cost if desired. aPriori chooses to use actual or virtual stock based on the part thickness.

Machine Selection

For all processes except the two-axis cutting processes, aPriori selects the feasible machine with the lowest overhead rate.

Overhead rate, here, is the sum of the machine properties **Direct Overhead Rate** and **Indirect Overhead Rate**:

Overhead Rate = Machine Direct Overhead Rate + Machine Indirect Overhead Rate

For the two-axis cutting processes (Laser Cut, OxyFuel Cut, Plasma Cut, and Waterjet Cut), aPriori selects the feasible machine with the lowest cut cost per part. The major component of cycle time that varies by machine is cut time (which is burn time, for laser, oxyfuel, and plasma), so machine selection picks the machine with the lowest cut cost per part:

Cut Cost per Part = (Labor Rate + Overhead Rate) * Cut Time

Here, cut cost per part is based on the following:

- Labor rate: specified by the machine property **Labor Rate**.
- Overhead rate: specified as described in [Direct and Indirect Overhead](#), except that the calculation here is implemented so as to take into account only those components of overhead that vary by machine.
- Cut time: cut length divided by cut rate, where
 - Cut length is the sum of blank perimeter and hole perimeters.
 - Cut rate (except for Waterjet cut rate) is looked up by machine power, part thickness, and material cut code in the lookup table **sheetMetalNestingCutRate**. The lookup finds the table row that exactly matches machine power and material cut code, and that has the smallest thickness value that is greater than or equal to the part thickness. The table value for **Feed Rate Small Features** is then selected for the calculation of cut cost.

Cut rate for Waterjet is calculated based on part thickness, the machine property **Pressure**, and the machine properties or setup options for **Orifice Diameter**, **Abrasive Flow Rate**, and **Mixing Tube Diameter**. The calculation uses an empirically validated formula.

aPriori selects only from preferred machines, if there is a feasible preferred machine and the cost model variable **usePreferredMachines** is set to **true** (the default in starting point VPEs). If there is no feasible preferred machine, or if the cost model variable

`usePreferredMachines` is set to `false`, `aPriori` selects from all machines. A machine is preferred if the machine property `isPreferred` (typically displayed as **Is Preferred**) is `true`.

Machine Feasibility

Following are the machine feasibility rules:

- **3D Laser**
 - Part length, width, and height do not exceed machine dimensions.
 - Blank thickness lies between the minimum and maximum thickness capabilities of the machine.
- **Bend Brake**
 - Bend length does not exceed machine dimensions.
 - Bend radius-to-thickness ratio does **not** exceed machine capability.
- **Laser Cut, OxyFuel Cut, Plasma Cut**
 - Blank fits on machine table length and width.
 - There is an entry in the lookup table `sheetMetalNestingCutRate` that exactly matches machine power and material cut code.
 - Material thickness falls within the range of thicknesses covered by the lookup table `sheetMetalNestingCutRate` for the machine's power and the current material's cut code.
- **Laser Punch, Plasma Punch**
 - Blank fits on machine table length and width.
 - Material thickness does not exceed the machine property **Max Sheet Thickness**.
 - Material thickness is not less than the minimum thickness that appears in the lookup table `sheetMetalNestingCutRate` for the machine's power and current material's cut code.
 - There is an entry in the lookup table `sheetMetalNestingCutRate` that exactly matches machine power and material cut code.
 - Required punch force (based on material shear strength, blank thickness, and largest hole perimeter) does not exceed machine's press force.
 - Part has no form whose length exceeds machine's maximum punch size.
 - Part has no form whose depth exceeds the machine's maximum form depth.
- **Waterjet Cut**
 - Blank fits on machine table length and width.
 - Machine properties or setup options provide all values necessary for the determination of cut rate (see above).
- **Cut -to-Length, Shear**
 - Material thickness does not exceed the machine's Max Thickness for the current material type.
- **Deslag**
 - None.
- **Turret Press**
 - Blank fits on machine table length and width.
- **2 Roll Bending**

- Part thickness does not exceed machine capability.
- Machine is capable of performing at least one bend.
- **3 & 4 Roll Bending**
 - Part thickness does not exceed machine capability.
 - Machine is capable of performing at least one bend.
 - Part weight does not exceed machine capability.
 - Length of the bend does not exceed machine max working length.
 - Bend diameter must be greater than machine single pass diameter (~1.3 x Top Roll Diameter)

Operation-level Feasibility and Routing

Below are the sheet metal operations that have associated feasibility rules, grouped by GCD type. Each operation is accompanied by necessary conditions for the operation's selection. aPriori checks the operations in the order specified by the operation templates, and selects the first operation for which the current GCD satisfies all the necessary conditions. Note that **Laser Punch** and **Plasma Punch** reflect the rules listed for **Laser Cut**, **Plasma Cut**, and **Turret Press**.

Blank

- *Punching*
 - Blank has at least one straight edge or at least one small, curved edge; that is, the blank either has at least one straight edge or has at least one non-straight edge whose minimum radius of curvature (**Min Convex Radius** or **Min Concave Radius**) is less than or equal to half the value of the machine property **Max Punch Size** (which specifies the diameter of the largest punch).

Complex Hole

- *3DLaserCutting*
 - Meets any GTOL tolerance requirements.
- *LaserCutting (also applies to Laser Punch)*
 - GCD is not flanged.
 - Meets any GTOL tolerance requirements.
- *OxyFuelCutting*
 - Hole diameter equals or exceeds minimum hole diameter.
 - Meets any GTOL tolerance requirements.
- *Perforating*
 - There are at least 19 other holes with the same perimeter and area as this hole.
 - There are at least two *nearby* holes with the same perimeter and area, where **a** is a *nearby* hole for **b** if and only if there is a **LIIES_NEAR** relation that relates **a** and **b** and that has a **distance** property less than or equal to:
 - **b**'s SER width, for holes whose **holeType** is **smallRectangular**
 - One and a half times **b**'s SER width, for holes whose **holeType** is **smallObround**
 - Diameter of **b**'s smallest enclosing circle times the value of the machine property **perforationProximityThreshold**, for holes whose **holeType** is **smallComplex**

- Meets any GTOL tolerance requirements.
- *PlasmaCutting (also applies to Plasma Punch)*
 - Hole diameter must exceed minimum hole diameter.
 - Meets any GTOL tolerance requirements.
- *Punching*
 - Hole's **SEC Diameter** (diameter of the hole's smallest enclosing circle) is less than or equal to the value of the machine property **Max Punch Size**.
- *WaterjetCutting*
 - GCD is not flanged or chamfered.
 - GCD is not flanged or chamfered
 - Ratio of wall thickness to part thickness is less than the plant variable **waterjetWallThicknessToDepthRatio**.
 - Hole width may not be less than the kerf width specified in the plant variable **waterjetKerf**.

Edge

- *Punching*
 - Edge either is straight or is curved and small; that is, the edge either is straight or is non-straight and has a minimum radius of curvature (**Min Convex Radius** or **Min Concave Radius**) that is less than or equal to half the value of the machine property **Max Punch Size** (which specifies the diameter of the largest punch).
- *Plasma Bevel Cutting*
 - GCD property **Edge Type** is Chamfer.
 - Plasma bevel cutting is enabled. By default in starting point VPEs, chamfers are assumed to be created by secondary machining, so plasma bevel cutting is disabled. VPE administrators can customize the default with the cost model variable **defaultPlasmaBevelCuttingStatus** (**true** for enabled or **false** for disabled). Users can override the default on a part-by-part basis with the setup option **Enable Plasma Bevel Cutting**—see [Plasma-Cut-specific Inputs](#).
 - If there are chamfers on both the top and bottom sides of the part, this chamfer is on the side of the part with the longest total chamfer length (otherwise the chamfer is assumed to be created by secondary machining).

Perimeter

- *Waterjet*
 - The perimeter GCD must be the one associated with the part height.

Simple Hole

- *3DLaserCutting*
 - GCD is not flanged.
 - GCD is not blind.
 - Meets any GTOL tolerance requirements.
- *LaserCutting (also applies to Laser Punch)*
 - GCD is not flanged.

- GCD is not blind.
- Meets any GTOL tolerance requirements.
- *OxyFuelCutting*
 - GCD is not threaded.
 - GCD is not countersunk.
 - GCD is not flanged.
 - GCD is not blind.
 - Meets any GTOL tolerance requirements.
- *Perforating*
 - There are at least three other holes with the same perimeter and area as this hole
 - There are at least two *nearby* holes with the same perimeter and area, where a is a *nearby* hole for b if and only if there is a **LIIES_NEAR** relation that relates a and b and that has a **distance** property less than or equal to b's diameter.
 - Meets any GTOL tolerance requirements.
- *PlasmaCutting (also applies to Plasma Punch)*
 - GCD is not flanged.
 - GCD is not blind.
 - Meets any GTOL tolerance requirements.
- *TurretPress (also applies to Laser Punch and Plasma Punch)*
 - GCD is not blind.
 - Meets any GTOL tolerance requirements.
- *Waterjet*
 - The hole axis must be parallel to the cut direction of the part perimeter.
 - GCD is not blind.
 - GCD is not countersunk.
 - GCD is not flanged.
 - Meets any GTOL tolerance requirements.
 - Ratio of wall thickness to part thickness is less than the plant variable `waterjetWallThicknessToDepthRatio`
 - Hole width may not be less than the kerf width specified in the plant variable `waterjetKerf`.

Straight Bend

- *Bending*
 - GCD is linear.
 - GCD has no formed gussets.
 - GCD does not intersect or end any other bend or form.
 - Minimum bend radius is greater than or equal to the product of the part's thickness and the cost model variable **minBendRadiusRatio** (0.5 in starting point VPEs).
 - Minimum bend radius is less than the cost model variable **maxBendBrakeRadius** (42mm in starting point VPEs).

- Bend length does not exceed the machine property **Max Bend Length**.
- Bend length is greater than or equal to both the stock height and the cost model variable **minBendLengthBendBrake** (10mm in starting point VPEs).
- Bend flap length does not exceed the bend's minimum bend radius plus 2.5 times the part thickness, unless the bend is part of a multibend (that is, unless it bears the LIES_NEAR relation to another bend, at a distance that is less than the bend's minimum bend radius plus 2.5 times the part thickness).
- **2 Roll Bending**
 - GCD is linear.
 - GCD is not inside a complex hole.
 - Bend radius must be greater or equal to the minimum radius for 2 roll bending ((plant variable **min2RollBendingDiameterRatio** * Top RollDiameter)/2).
 - GCD length is less than the maximum Roll Working Length.
- **3 & 4 Roll Bending**
 - GCD is linear.
 - GCD is not inside a complex hole.
 - Bend radius must be greater or equal to the minimum radius for 3 roll bending (machine variable Minimum Single Pass Diameter)/2).
 - GCD length is less than the maximum Roll Working Length.

Chemical Milling

Chemical milling is a non-traditional, subtractive manufacturing process in which material is removed by means of a strong, temperature-regulated chemical etchant. aPiori cost models support chemical milling of sheet metal parts that use the **CTL/Shear/Chemical Mill** routing, that is, parts that are first subject to the Cut-to-length, Shear, and (optionally) Roll Bending processes. Chemical Milling must be manually assigned to a part. See [Routing a Part to Chemical Milling](#).

Note: Do not attempt to use Chemical Milling with any routing other than **CTL/Shear/Chemical Mill**. Chemical Milling with other primary routings will fail to cost.

Chemical milling involves submersing the cutting areas in a corrosive chemical known as an etchant, which reacts with the material in the area to be cut and causes the solid material to be dissolved; inert substances known as maskants are used to protect specific areas of the material.

Within aerospace applications, chemical milling is typically used on large sheet metal components to reduce the overall weight of the component. Common examples of this can be found on wing or fuselage skin panels where areas not being fastened to ribs or stringers are reduced in thickness.

The rate of chemical etching is slow in comparison with traditional milling machine removal rates. However, the advantages are that it can be applied to very large, complex shapes where a large amount of material is removed. Also, the etching time is a function of the pocket depths rather than the number of pockets being milled, therefore many features of the same depth can be etched simultaneously.

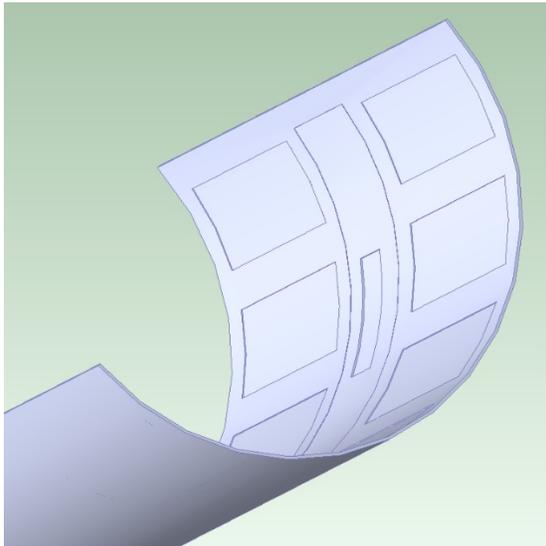
Chemical Milling GCDs

When a part is routed to Chemical Milling, Form GCDs that are of type STAMP are automatically assumed to be created by chemical milling, and are assigned to Chemical Milling operations. These GCDs are pocket-like regions whose floor and walls satisfy all the following:

- Floor consists of a region of thinner (lower gauge) material (compared to elsewhere on the blank).
- Floor is parallel to the opposite side of the part.
- Walls have a height that is less than or equal to the gauge reduction.
- Walls are perpendicular to the floor.
- Walls form a sharp angle with the surrounding blank.

Note that the walls can have a 90 degree fillet with the floor, or can consist entirely of a 90 degree fillet.

Note also that a pocket can be located within another, shallower pocket.



Users can also manually assign surface GCDs (Curved Surfaces, Curved Walls, and Planar Faces) to Chemical Milling—see [Assigning Chemical Milling to a Surface GCD](#).

Chemical Milling Process Overview and Routing

Chemical Milling routings include the following processes in the following order. These processes (except Mask Spray) are part of the Machining process group:

- Bench Operation: This process has as children several operations (cleaning, identifying, line sealing, spark testing, and final inspecting) that are performed at the same work area, though they are performed at disparate times during the execution of the routing. See [Machine Selection for Bench Operation](#), [Bench Operation Formulas](#), and [Bench Operation Options](#).

Chemical Milling routings begin with the following Bench operations, which are performed on the Blank GCD:

- Cleaning: the entire part is cleaned in order to ensure that material will be removed uniformly from the surfaces to be etched. The cost model assumes the use of Diestone SR (PF-SR) Wipes. The unit cost of wipes is specified by a toolshop variable.
- Identing: a unique identifier is vibro-etched onto the part. By default, the time required is specified by a cost model variable; a setup option allows users to override the default.
- Mask Spray: a protective coating (maskant) is applied (by spraying) to all portions of the part surface. This maskant is made of a material that is chemically resistant to the etchant. The cost model assumes the use of AC-850-AERO-D-TAN. Maskant unit cost is specified by a toolshop variable. A setup option allows users to customize the number of maskant layers, as well as the programming cost. This process is part of the Surface Treatment process group—see [Mask Spray Machine Selection](#), [Mask Spray Formulas](#), and [Mask Spray Inputs](#).
- Mask Cure: the maskant is developed (cured) either in a heated oven or in an ambient-temperature drying room—a setup option allows the user to specify which. By default, the time required is looked up in a lookup table; a setup option allows users to override the default time. See [Machine Selection for Mask Cure](#), [Mask Cure Formulas](#), and [Mask Cure Options](#).
- Scribe: scribe lines are cut in the maskant along the perimeter of each GCD to be etched, in preparation for selective removal of maskant during etching. Scribing is performed on all GCDs, before any GCD is etched. The cost model assumes the use of a five-DOF robotic system with flexible fixtures and carbon dioxide laser. A setup option allows the user to customize the programming cost. See [Machine Selection for Scribe](#), [Scribe Formulas](#), and [Scribe Option](#).
- Bench Operation: see Bench Operation, above. The following operations are performed after scribing and prior to etching:
 - Cleaning: performed on the Blank GCD. The part is cleaned to remove maskant dust created by the scribing operation.
 - Line Sealing: scribe lines are manually resealed. One execution of the Line Sealing operation, performed on the Blank GCD, uses a roller to apply line sealing solution to the surface of the entire part. Then additional executions of the Line Sealing operation use a brush to apply line sealing solution to scribed pocket edges. There is one such additional execution for each scribed pocket.
 - Spark testing: performed to detect pinholes in the maskant. A setup option allows customization of the time required.
- Etch Cell: This process performs one or more Etch Cell Cycle operations, followed by desmut and desmut rinse procedures. Pockets are grouped by depth (pockets in the same group have the same depth), and there is one Etch Cell Cycle for each group. During each cycle, the following operations are performed:
 - Pocket Peeling: at the beginning of each cycle, the maskant is peeled away from the pockets in the cycle's associated group.
 - Pocket Etching: following pocket peeling, the part is immersed in an etchant that chemically attacks those portions of the part surface that are not masked. When the desired amount of material has been removed, the part is

withdrawn from the etchant. A setup option allows customization of the etching rate.

- Rinsing: following etching, the part is rinsed to stop the etching process.
- Drying: following rinsing, the part is dried.
- Depth Inspection: at the end of each cycle, the depths of the pockets are checked for depth tolerance.

The deepest pockets are etched in the first cycle, as well as in every subsequent cycle; the shallowest pockets are etched only in the final cycle. All pockets are etched to their final depth in the final cycle.

See [Machine Selection for Etch Cell](#), [Etch Cell Formulas](#), and [Etch Cell Options](#).

- **Remove Mask:** any remaining maskant is removed from the component, and then the pocket edges are manually dressed. This is performed by the following operations:
 - **Removing Residual Maskant:** performed on the Blank GCD after all etching is complete.
 - **Dressing Edges:** performed on each etched pocket.

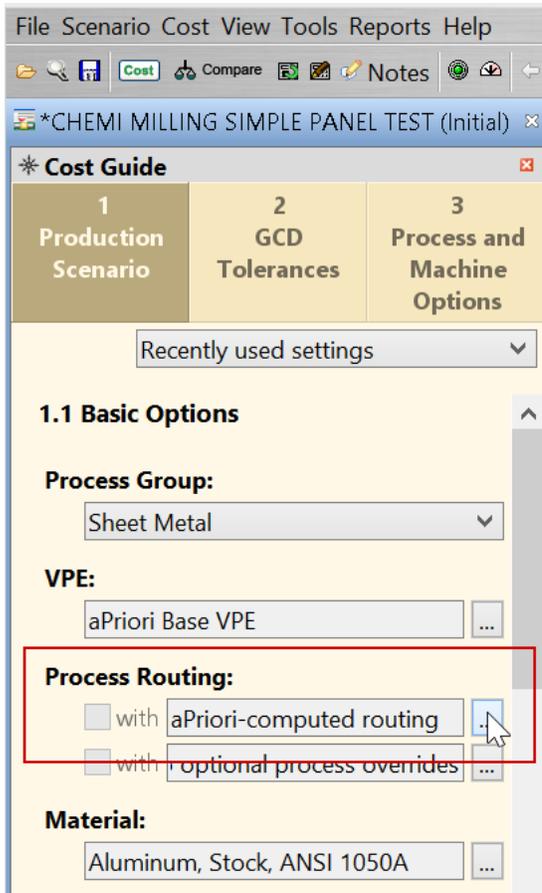
See [Machine Selection for DeMask](#) and [DeMask Formulas](#).

- **Bench Operation:** See [Bench Operation](#), above.
 - **Final Inspecting:** performed on the Blank GCD.
- **5-Axis Mill:** the part is routed to the 5-Axis Mill process in order to trim the blank addendum (which is added for ease of transportation and protection from the etchant), as well as to create the part's holes (if there are any).

Routing a Part to Chemical Milling

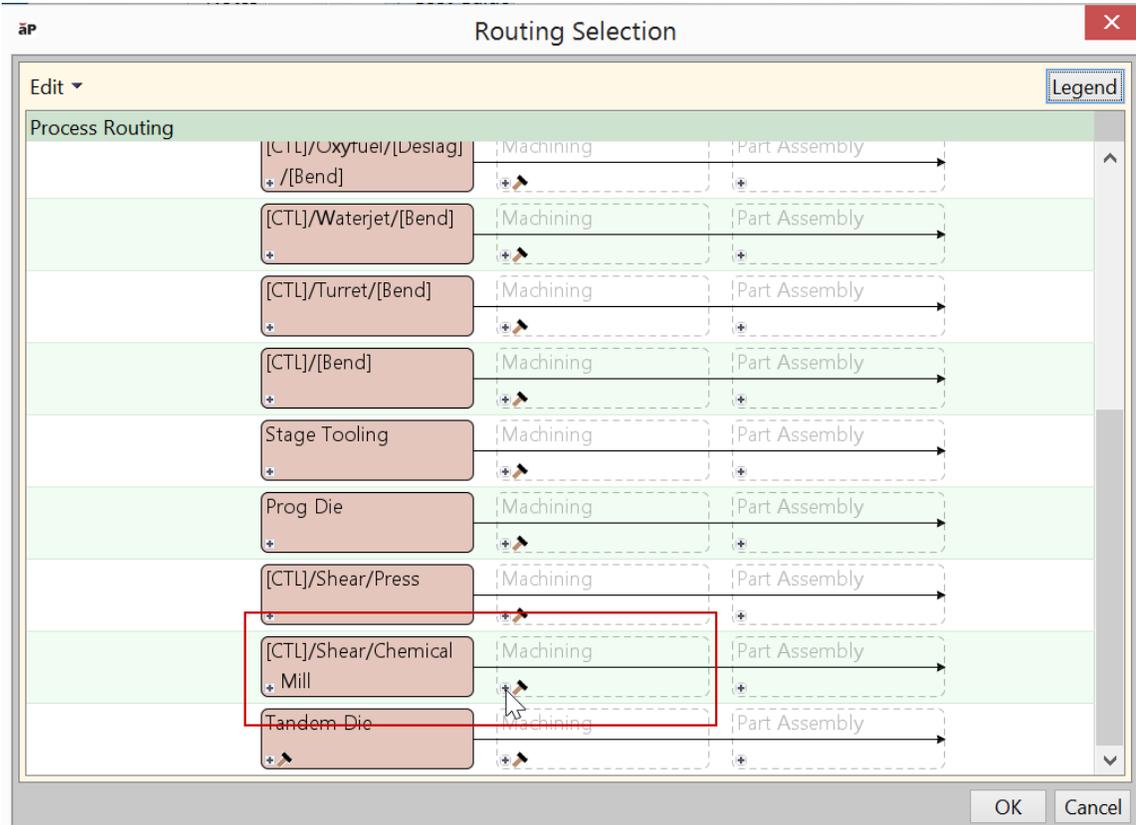
When you route a part to Chemical Milling, Form GCDs that are of type STAMP are automatically assumed to be created by chemical milling, and are assigned to Chemical Milling operations (see [Chemical Milling GCDs](#)). To route a part to Chemical Milling, follow these steps:

- 1 In the Production Scenario tab of the Cost Guide, click the ellipsis, ..., next to **aPriori-computed routing** in the Process Routing section:

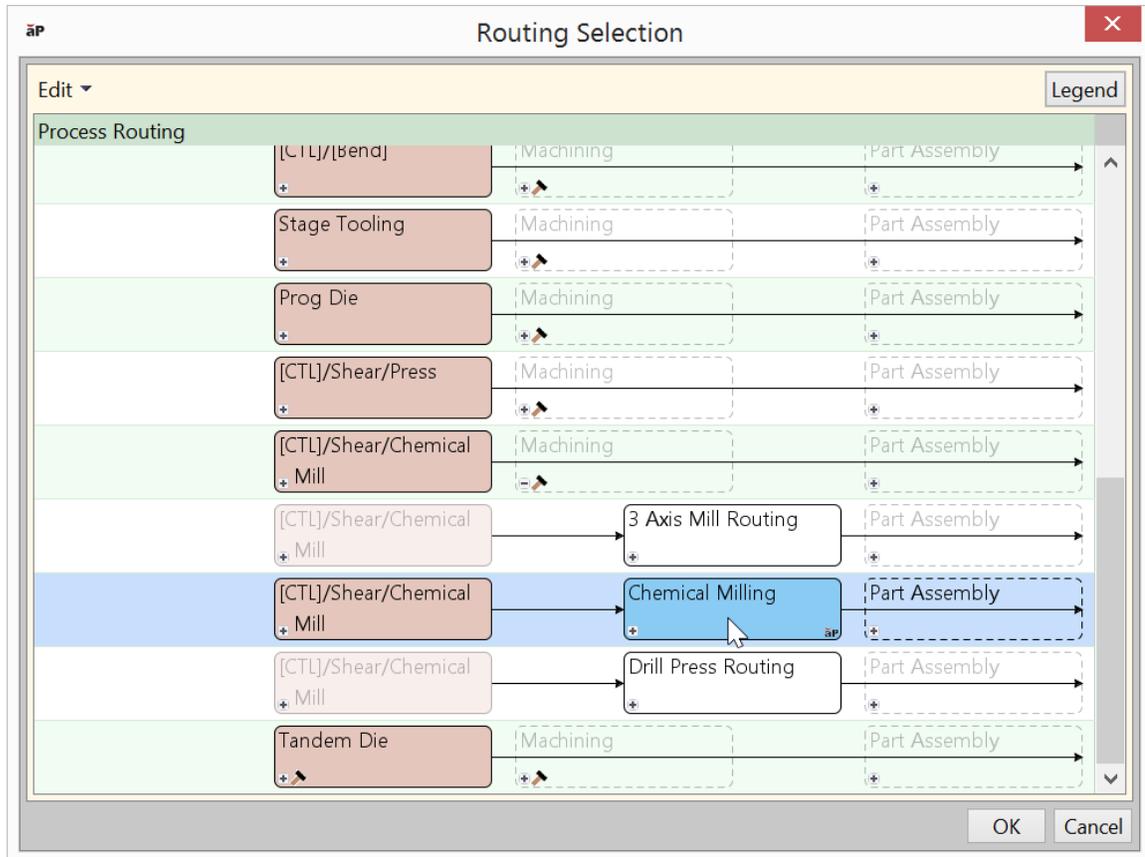


The Routing Selection dialog appears.

- 2 In the Routing Selection dialog, scroll down if necessary, and click the + to expand the **Machining** node next to the **CTL/Shear/Chemical Mill** node:



The node expands to reveal multiple **CTL/Shear/Chemical Mill** routings:



- 4 Click OK.

Note: If you expand the **Machining** node next to nodes *other than* **CTL/Shear/Chemical Mill**, a routing with a **Chemical Milling** node is among the revealed routings. Do *not* attempt to use any routing with a **Chemical Milling** node other than the **CTL/Shear/Chemical Mill** routing. Chemical Milling with other routings will fail to cost.

See also [Assigning Chemical Milling to a Surface GCD](#).

Assigning Chemical Milling to a Surface GCD

When a part is routed to Chemical Milling, Form GCDs that are of type **STAMP** are automatically assumed to be created by chemical milling, and are assigned to Chemical Milling operations (see [Chemical Milling GCDs](#)). You can also manually assign surface GCDs (Curved Surfaces, Curved Walls, and Planar Faces) to Chemical Milling. When you do this, you can use a setup option to specify the depth to which you want the surface etched (that is, the depth of material to be removed by etching). If you don't enter an etch depth, the cost model uses the depth of the shallowest form of type **STAMP**, if there is one; otherwise, the cost model uses 50% of the blank thickness.

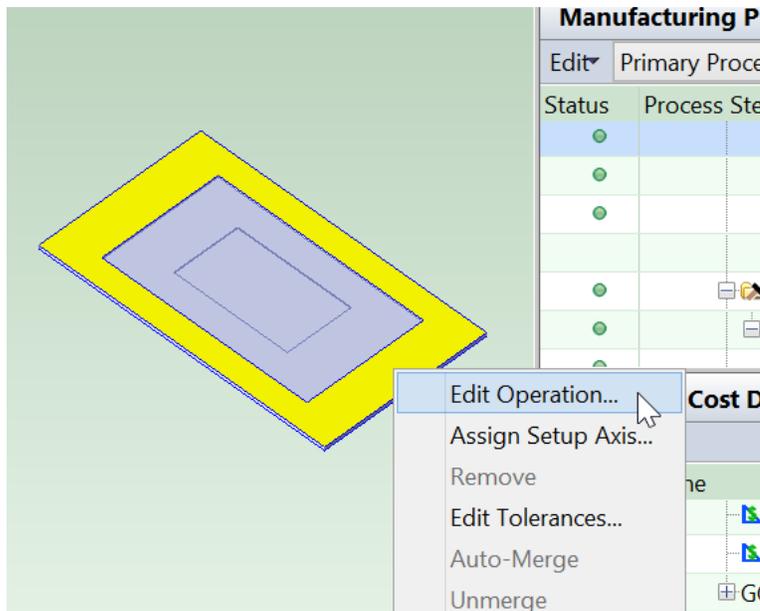
Follow these steps to assign Chemical Milling and enter an etch depth:

- 1 Ensure that the part has been routed to Chemical Milling (see [Routing a Part to Chemical Milling](#)), and costed at least once.

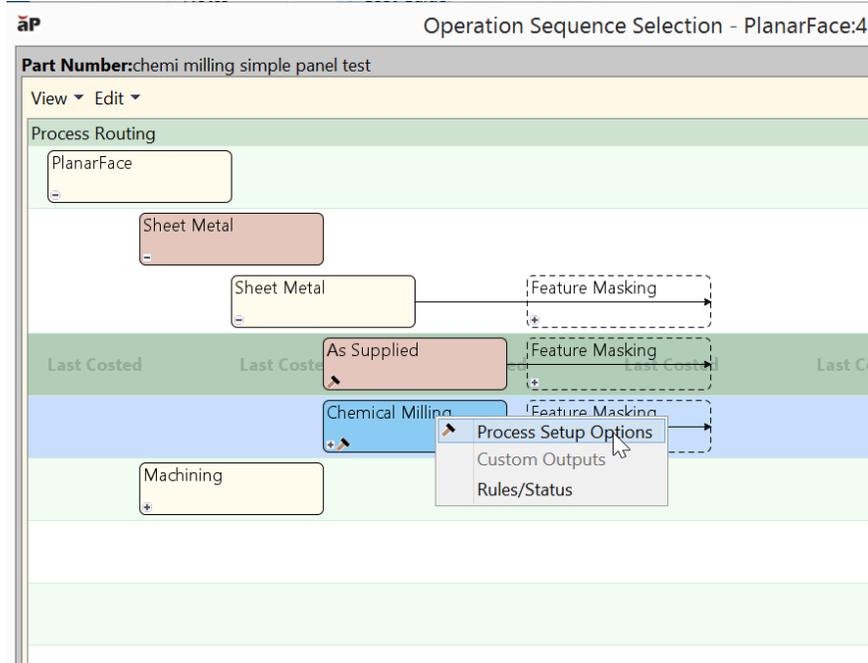
Note: If your part has no Form GCDs of type **STAMP**, you must disable process-level feasibility checks, cost the part, and then follow the steps in this section. Be sure to

disable feasibility checks on both the **CTL/Shear/Chemical Mill** process node and the **Chemical Milling** process node: in the Routing Selection dialog, right-click each node, select **Rules/Status**, and then uncheck the checkbox in the dialog that appears.

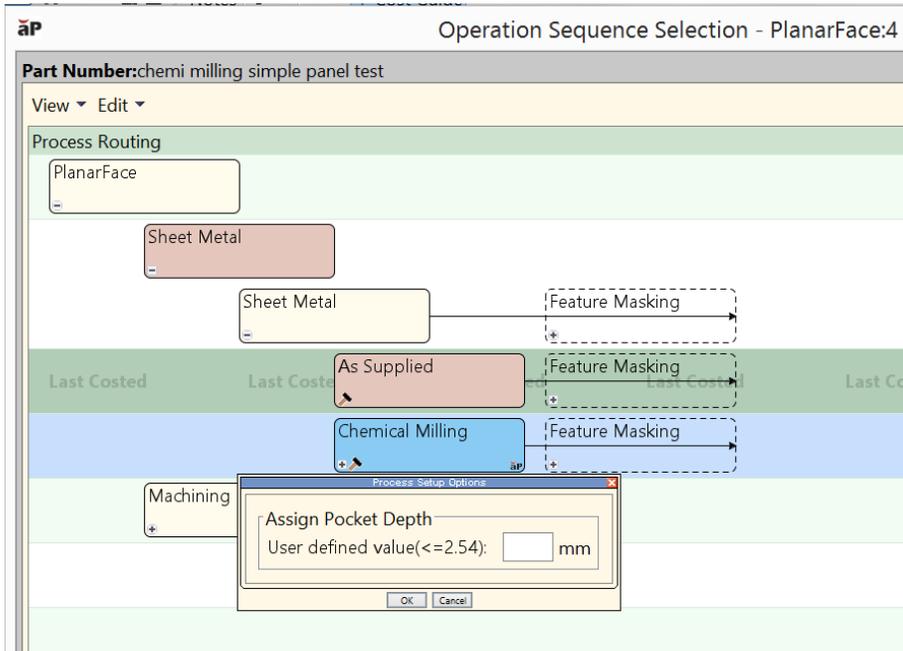
- In the Viewer, select the surface that you want to assign to Etching (the surface must be orthogonal to the depth direction). Then right click in the Viewer, and select **Edit Operation....**



- In the Operation Sequence Selection dialog, click **Chemical Milling** to select that operation sequence. Then right click **Chemical Milling** and select **Process Setup Options**.



- 4 Enter the depth of the pocket that you want to be created, that is, the depth of material to be removed by etching. Click **OK**.



Cost Algorithms and Calculations

If machining processes are included as secondary processes on sheet metal components, then the machining costs are computed via the **Machining** cost model and combined with the **Sheet Metal** process costs to produce a total manufacturing process cost.

This section details how costs are calculated by aPriori. Note that you can override the calculation of many of the quantities involved, and specify them explicitly—see [User Inputs](#), below.

When not otherwise specified, costs are per part.

This section covers formulas in the following areas:

- [Material Cost and Utilization](#)
- [Deslag](#)
- [Bend Brake](#)
- [Laser Cut, Oxy Fuel Cut, Plasma Cut](#)
- [Waterjet Cut](#)
- [3D Laser](#)
- [Cut-to-Length, Shear](#)
- [Turret Press](#)
- [Roll Bending \(2-, 3-, and 4-roll\)](#)

Material Cost and Utilization

The material cost of a sheet metal part is based on rough mass required to make the part. The utilization is equal to the finish mass of the part divided by the rough mass—rough mass includes any material scrap.

The **Material Selection** dialog (in the Manufacturing Process pane) provides you with four options for calculating utilization:

- **Rectangular Nesting:** assumes the part is nested on a sheet based on its bounding box. In this case, the rough mass is equal to the total mass of the sheet divided by the number of parts nested on the sheet.
- **True-Part Nesting:** uses the component's actual perimeter to determine nesting, and tests various rotations of the component. See [User Inputs](#) for information on **Step Angle for True-Part Shape Nesting**. True-part nesting is the default utilization method for baseline VPEs (but see the plant variable **defaultUtilizationMethod**), since it usually results in closer nesting, yielding higher material utilization.
- **Machine Default:** uses the current machine's associated average material utilization (the machine property **Avg Utilization**); use this to estimate material costs for dynamic nesting.
- **Override:** uses a fixed utilization value entered by user; use this when you know the exact utilization based on a supplier's nesting pattern.

The current nesting pattern on the currently selected stock is viewable in the Viewer using the **Analysis** menu. The stock can be changed via the **Material Selection** dialog.

You can display the flat pattern head on, in a separate window, together with its associated SER, by selecting **Flat Outline** from the Analysis menu in the Viewer toolbar.

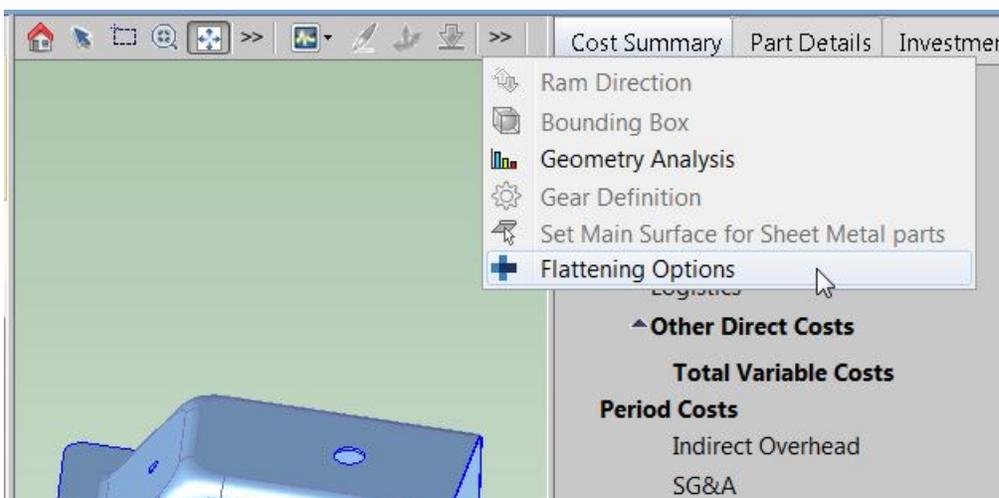
Flattening

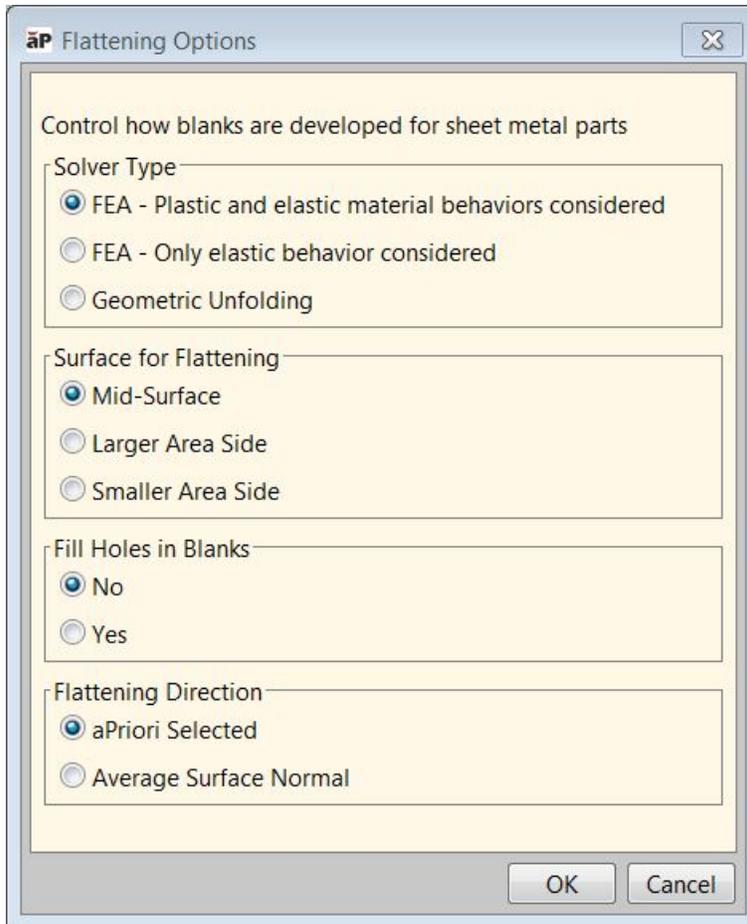
aPriori provides two alternative methods for determining the outline of the flattened part, finite element analysis (FEA)-based flattening and geometric flattening:

- FEA flattening:
 - Analysis is based on a forming simulation which uses a finite element analysis derived from the part's CAD model and the properties of the selected material.
 - More accurate than geometric flattening for formed and drawn automotive components and similar complex stampings.
 - Generally slower than geometric flattening (very complex parts sometimes require more than one minute to flatten, although the great majority require far less time).
- Geometric flattening:
 - Analysis is based on unfolding of CAD model geometry, and neither takes into account material properties nor simulates the forming process.
 - Accurate for “mostly developable” parts, that is, parts consisting primarily of flat planar surfaces and simple bent or rolled surfaces, with a few small, isolated deformed features like gussets and stiffening beads. These types of parts are common in the agriculture/construction equipment and hi-tech industries.
 - Generally faster than FEA flattening.

FEA flattening is used by default in starting point VPEs. VPE administrators can customize this default with the site variable **flatteningSolverType**.

For a given part, you can override the default flattening method, or configure FEA flattening, with the Flattening Options dialog, which is available from the Viewer toolbar.





The dialog provides the following options:

- Solver Type:
 - FEA – Plastic and elastic material behaviors considered: takes into account both the elasticity-related material properties (including Young’s modulus and Poisson’s ratio) and the plasticity-related material properties (including K, the strain-hardening coefficient, N, the strain-hardening exponent, and R, the Lankford parameter, average) . This is the default in starting point VPEs.
 - FEA – Only elastic behaviors considered: takes into account only the elasticity-related material properties (including Young’s modulus and Poisson’s ratio). Because only elastic behavior is modeled, blank size estimates are slightly larger with this option than with the “Plastic and elastic” option. Some users prefer this approach as it is slightly more conservative for estimating material usage and costs.
 - Geometric Unfolding: Select this if you don’t want to use FEA flattening.

The **Flattening Method** property of the Blank GCD indicates the method used for the most recent geometry extraction. It’s possible values are FEA_PLASTIC, FEA_ELASTIC, GEOMETRIC_UNFOLDING.

Geometric Cost Drivers			
Show ▾			
Status	Name	O... Name	Property Result
●	Component	Num Edges	17
●	Base Properties [1]	Num Sharp Corners	-
●	Blank [1]	Straight Length (mm)	1,138.65
●	Blank2	Flattening Method	FEA_PLASTIC
●	Edge:79	Worst Peninsular Ratio	0.00
●	Edge:80	Worst Peninsular Ratio	0.00
●	Edge:81	Requested	<auto-select>
●	Edge:82	Selected	Blanking / Direct Trimmin...

VPE administrators can customize the default solver type with the site variable **flatteningSolverType**.

- Surface for Flattening: applies to FEA flattening only. FEA flattening proceeds by imposing a mesh on an overall surface of the part. The mesh serves to divide the part into a large but finite number of discrete elements.
 - Mid-Surface: specifies that the mesh should be imposed midway between one side of the part material and the other side of the part material. A mid-surface mesh basically represents the neutral surface of the part. This is the default in starting point VPEs.
 - Larger Area Side: specifies that the mesh should be imposed on the larger-area side of the part material.
 - Smaller Area Side: specifies that the mesh should be imposed on the smaller-area side of the part material.

VPE administrators can customize the default surface for flattening with the site variable **flatteningSurface**.

- Fill Holes in Blanks: applies to FEA flattening only.
 - No: specifies that the mesh (see Surface for Flattening, above) should not be applied to portions of the material surface that will be removed to form a hole. This is the default in starting point VPEs.
 - Yes: specifies that the mesh (see Surface for Flattening, above) should be applied to portions of the material surface that will be removed to form a hole.

VPE administrators can customize the default with the site variable **flatteningFillHoleMethod**.

- Flattening Direction: applies to FEA flattening only.
 - aPriori Selected: specifies that the flattening calculation should be based on the ram direction chosen by aPriori. This option is available only in the Sheet Metal—Transfer Die process group, and is the default in starting point VPEs. See [Ram Direction for Transfer Die](#) for more information.
 - Average Surface Normal: specifies that the flattening calculation should be based on a ram direction that is the average direction of the normal to the part's surfaces. This is the only option available in the Sheet Metal process group.

VPE administrators for Sheet Metal—Transfer Die can customize the default flattening direction with the site variable **flatteningDirection**.

VPE Administrators also can customize the FEA flattening behavior with the following site variables:

- **flatteningInitialStrainValue** (0.002 in starting point VPEs): for FEA flattening, specifies the strain present in the material before outside forces and loads are applied.
- **flatteningTimeoutSeconds** (600 seconds in starting point VPEs): determines how long FEA flattening will run before timing out; if FEA flattening times out or fails for any reason, an FEA-failure message appears in the Viewer, and geometric flattening is used instead. A value of 0 indicates no timeout—FEA flattening will run indefinitely.

As mentioned above, FEA flattening takes into account material properties, including the following:

- Young's Modulus
- Poisson's Ratio, K (strain-hardening coefficient)
- N (strain-hardening exponent)
- R (Lankford parameter, average).

Materials in starting point VPEs specify these properties. If your VPE includes a material that doesn't specify these properties, aPriori uses the following default values based on material type:

Material Type	Young's Modulus (MPa)	Poisson Ratio	K (strain-hardening coefficient, Mpa)	N (strain-hardening exponent, MPa)	R (Lankford parameter, average)
Aluminum	69000	0.33	341.1	0.21	0.7
Copper	115000	0.33	317	0.54	0.99
Galvanized Steel	207000	0.28	543	0.21	0.99
Stainless Steel	207000	0.28	1426	0.502	1
Steel	207000	0.28	0.28	479.3	1.345

If the material type is not one listed in the table above, the entries for Steel are used.

True-part Nesting and Very Small Parts

True-part nesting usually uses both rectangular and grid nesting algorithms, but only grid nesting is used for parts that are very small compared to the sheet in which they are nested. Rectangular nesting, while it adds to nesting accuracy, can be very slow for such parts. VPE administrators can use the cost model variable **highResolutionNestingFactor** to adjust the threshold for identifying such parts and controlling which algorithms are used.

In starting point VPEs, **highResolutionNestingFactor** is set to 0.25, indicating that only grid nesting is used for parts whose surface area is less than one quarter of one percent of

the area of the stock sheet. By decreasing this value, you can increase nesting accuracy, but you might also increase the amount of time required for the nesting calculations.

Formulas

Material Cost = Raw Material Cost – Scrap Material Credit – Scrap Part Credit

Material Cost depends on the following:

- Raw material cost: see formula
- Scrap material credit: this is 0 if the setup option [Enable Scrap Material Credit](#) is un-checked (the default in starting point VPEs). Otherwise, it is specified by the formula below.
- Scrap part credit: this is 0 if the setup option [Enable Scrap Part Credit](#) is un-checked (the default in starting point VPEs). Otherwise, it is specified by the formula below.

Raw Material Cost = (Material Cost Per Mass * Rough Mass) / Final Yield

Raw material cost is the cost of material for one part, including the cost of scrap produced during manufacture of the part, as well as the amortized cost of scrapped parts. It depends on the following:

- Material cost per mass: specified by the material property **Cost per KG**.
- Rough mass: see formula.
- Final yield: see [Yields for Sheet Metal](#).

Rough Mass = Finish Mass / Utilization

Rough mass depends on the following:

- Finish mass: product of part **Volume** and material **Density**.
- Utilization: calculated by the cost engine. This is part mass divided by stock mass. See [Material Cost and Utilization](#).

Utilization = Utilization Edge Scrap * Utilization Part Scrap

Utilization is the product of the following:

- Utilization edge scrap (see formula below)
- Utilization part scrap (see formula below)

Utilization Edge Scrap = (Number of Parts Per Sheet * Blank Width * Blank Length) / (Sheet Length * Sheet Width)

Utilization edge scrap is a function of the following:

- Number of parts per sheet (calculated based on part geometry, nesting type, and sheet dimensions)
- Blank width (obtained from GCD extraction)
- Blank length (obtained from GCD extraction)
- Sheet length (see the **Material Stock** section of the Material Selection dialog)
- Sheet width (see the **Material Stock** section of the Material Selection dialog)

$$\text{Utilization Part Scrap} = \frac{\text{Part Volume}}{(\text{Blank Length} * \text{Blank Width} * \text{Part Thickness})}$$

Utilization part scrap is a function of the following:

- Part volume (obtained from GCD extraction)
- Blank length (obtained from GCD extraction)
- Blank width (obtained from GCD extraction)
- Part thickness (obtained from GCD extraction)

$$\text{Scrap Material Credit} = \text{Material Cost Per Mass} * \text{Scrap Cost Percent} * \text{Scrap Mass}$$

Scrap material credit is the product of the following:

- Material cost per mass: specified by the material property **Cost per KG**.
- Scrap cost percent: this is 0 if the setup option [Enable Scrap Material Credit](#) is un-checked (the default in starting point VPEs). Otherwise, it is specified as a percentage by the material property **Scrap Cost Percent**.
- Scrap mass: see formula.

$$\text{Scrap Mass} = \text{Rough Mass} - \text{Finish Mass}$$

Scrap mass depends on the following:

- Rough mass: see formula.
- Finish mass: product of part **Volume** and material **Density**.

$$\text{Scrap Part Credit} = \frac{(\text{Material Cost per Kg} * \text{Scrap Cost Fraction}) * ((\text{Number of Scrap Parts} + \text{Number of Scrap Parts Down Stream}) * \text{Rough Mass})}{\text{Total Production Volume}}$$

Scrap part credit is 0 if the setup option [Enable Scrap Part Credit](#) is set to **false**. Otherwise, it is the product of the following:

- Material cost per mass: specified by the material property **Cost per KG**.
- Scrap cost fraction: this is 0 if the setup option [Enable Scrap Part Credit](#) is un-checked (the default in starting point VPEs). Otherwise, it is specified as a percentage by the material property **Scrap Cost Percent**.
- Number of scrap parts: number of parts discarded as scrap by this process. See [Yields for Sheet Metal](#).
- Number of scrap parts down stream: number of parts discarded as scrap by downstream processes. See [Yields for Sheet Metal](#).
- Rough mass: see formula.
- Total production volume: specified in the Production Scenario tab of the Cost Guide.

Yields for Sheet Metal

Sheet Metal processes use the following formulas:

Final Yield = Final Output Volume / Local Input Volume

Final yield affects material, labor, and overhead costs per part. It is the fraction of parts created by this process in the current production scenario that will survive as good parts once any secondary processes are completed. That is, final yield is the fraction of parts created by this process that are *not* discarded as scrap parts, either by this process or by a downstream process. Final yield depends on the following:

- Final output volume is the number of parts created by this process that are *not* discarded as scrap parts, either by this process or by a downstream process. It is the product of the annual volume and number of production years, specified in the Production Scenario screen of the Cost Guide.
- Local Input volume (see the formula below). This is the total number of parts produced by this process, including all parts discarded as scrap from this process or downstream processes.

Local Input Volume = Local Output Volume + Number of Scrap Parts for This Process

Local input volume is the total number of parts produced by this process in the current scenario, including all parts discarded as scrap from this process or downstream processes. It is the sum of the following:

- Local output volume (see the formula below). This is the number of parts produced by this process, excluding parts discarded as scrap by this process, but including parts that are discarded as scrap by downstream processes.
- Number of scrap parts for this process (see the formula below)

Local Output Volume = Final Output Volume + Number of Scrap Parts Downstream

Local output volume is the number of parts produced by this process in the current scenario, excluding parts discarded as scrap by this process, but including parts that are discarded as scrap by downstream processes. It is the sum of the following:

- Final output volume is the number of parts created by this process that are *not* discarded as scrap parts, either by this process or by a downstream process. It is the product of the annual volume and number of production years, specified in the Production Scenario screen of the Cost Guide
- Number of Scrap Parts Downstream. This the number of parts discarded as scrap by downstream processes.

Number of Scrap Parts for This Process = (Local Output Volume / Local Good Part Yield) – Local Output Volume

Number of scrap parts for this process is the number of parts produced by this process in the current scenario that are discarded as scrap by this process, before any downstream process is performed on them. It is a function of the following:

- Local output volume (see the formula above). This is the number of parts produced by this process, excluding parts discarded as scrap by this process, but including parts that are discarded as scrap by downstream processes.
- Local good part yield (specified by the machine property **Good Part Yield**). This is the fraction of parts produced by this process that are not discarded as scrap by this process but may be discarded as scrap by downstream processes.

Deslag

aPriori uses the formulas below to determine costs associated with this process.

Accounting Calculations

Labor Time = Cycle Time * Machine Labor Time Standard

Labor time is the product of the following

- Cycle time (see Cycle Time Calculation)
- Machine labor time standard (specified as a machine property). This value reflects the amount of time spent by machine operators in between machine cycles, including time performing maintenance and cleaning tasks as well as time pausing between tasks. The amount is expressed as a cycle time multiplier.

Labor Cost = (Labor Time / 3600) * Machine Labor Rate

Labor cost is a function of the following:

- Labor time (see formula above)
- Machine labor rate (specified by a machine property)

Direct Overhead Cost = (Labor Time / 3600) * Machine Overhead Rate

Direct overhead cost depends on the following:

- Labor time (see formula above)
- Machine overhead rate (specified as a machine property)

Amortized Batch Setup = (Machine Setup Time * (Machine Labor Rate + Direct Overhead Rate)) / Batch Size

Amortized batch setup cost depends on the following:

- Machine setup time (specified as a machine property)
- Machine labor rate (specified as a machine property)
- Direct overhead rate (see [Direct and Indirect Overhead](#))

Cycle Time Calculation

Cycle Time = Part Edge Perimeter + Machine Perimeter Allowance

Cycle time is the sum of the following:

- Part edge perimeter (sum of the perimeters of each GCD operated on)
- Machine perimeter allowance (time per unit length, specified as a machine property)

Bend Brake

aPriori uses the formulas below to determine costs associated with this process.

Accounting Calculations

Labor Time = Cycle Time * Machine Labor Time Standard * Machine Labor Ratio

Labor time is the product of the following

- Cycle time (see [Cycle Time Calculation](#))

- Machine labor time standard (specified as a machine property). This value reflects the amount of time spent by machine operators in between machine cycles, including time performing maintenance and cleaning tasks as well as time pausing between tasks. The amount is expressed as a cycle time multiplier.
- Machine labor ratio (specified as a machine property)

$$\text{Labor Cost} = ((\text{Labor Time} / 3600) * \text{Machine Labor Rate}) / \text{Process Yield}$$

Labor cost is a function of the following:

- Labor time (see formula above)
- Machine labor rate (specified as a machine property)
- Process yield (see formula below)

Amortized Batch Setup =

$$(\text{Machine Setup Time} * (\text{Machine Labor Rate} + \text{Direct Overhead Rate})) / \text{Batch Size}$$

Amortized batch setup is a function of the following:

- Machine setup time (specified as a machine property)
- Machine labor rate (specified as a machine property)
- Direct overhead rate (see [Direct and Indirect Overhead](#))

$$\text{Period Overhead} = \text{Labor Cost} * \text{Machine Period Overhead Coefficient}$$

Period overhead is the product of the following:

- Labor cost (see formula above)
- Machine period overhead coefficient (specified as a machine property)

$$\text{Process Yield} = 1 / (\text{Machine Process Yield}/100)$$

Process yield depends on the machine property **Process Yield**.

Cycle Time Calculation

$$\text{Cycle Time} = \text{Load and Unload Time} + \text{Number of Bends} * (\text{Bending Time} + \text{Part Manipulation Time})$$

Cycle time depends on the following:

- Load and unload time (obtained from lookup table—see below; increases with part mass, which increases with material density).
- Number of bends (obtained from GCD extraction)
- Bending time (specified as a machine property)
- Part manipulation time (obtained from lookup table—see below; increases with part mass, which increases with material density)

Load and unload times and manipulation times by part mass are contained in the lookup table **bendBrakeHandling**.

Laser Cut, Oxy Fuel Cut, Plasma Cut

aPiori uses the formulas below to determine costs associated with these processes.

Accounting Calculations

Labor Time = Cycle Time * Machine Labor Time Standard

Labor time is the product of the following

- Cycle time (see Cycle Time Calculation below)
- Machine labor time standard (specified as a machine property). This value reflects the amount of time spent by machine operators in between machine cycles, including time performing maintenance and cleaning tasks as well as time pausing between tasks. The amount is expressed as a cycle time multiplier.

Labor Cost = Labor Time * Machine Labor Rate

Labor cost is a function of the following:

- Labor time (see formula above). aPriori converts labor time from seconds to hours for use in this formula, since machine labor rate is
- Machine labor rate (specified as a machine property)

Amortized Batch Setup = (Machine Setup Time * (Machine Labor Rate + Direct Overhead Rate)) / Batch Size

Amortized batch setup cost depends on the following:

- Machine setup time (specified as a machine property)
- Machine labor rate (specified as a machine property)
- Direct overhead rate (see [Direct and Indirect Overhead](#))

Period Overhead = Labor Cost * Machine Period Overhead Coefficient

Period overhead is the product of the following:

- Labor cost (see formula above)
- Machine period overhead coefficient (specified as a machine property)

Cycle Time Calculation

Cycle Time = (Burn Time + Pierce Time + Rapid Traverse Time + Scrap Cutting Time + Shuttle Time) / Machine Number of Heads

Cycle depends on the following:

- Burn time, which depends on the following:
 - Cross-section thickness
 - Material type—aluminum, for example, cuts faster than steel
 - Machine wattage
 - Blank size
 - Feature perimeters—burn time increases with hole size.
 - Feature radii of curvature—tighter cuts are slower. (See also `minStraightRadius` in [Process Defaults and Thresholds](#).)
- Pierce time, which depends on the following:
 - Number of holes
 - Cross-section thickness

- Material type
- Machine wattage
- Rapid traverse time, which depends on the following:
 - Blank size
 - Machine's rapid traverse feed rate
- Scrap cutting time
- Shuttle time (increases with blank size)
- Machine number of heads (specified as a machine property)

Pierce and burn cutting rates by machine watts and material type and thickness are contained in the following lookup tables:

- Laser smNestingCutRate
- Plasma smNestingCutRate
- OxyFuel smNestingCutRate

Waterjet Cut

Waterjet cut is very similar to **Laser cut**, with the following differences:

The cycle time for the **Waterjet cut** process is calculated from the following times:

- Sum of individual feature cut times
- Pierce time
- Rapid traverse time

Waterjet cycle time calculations depend on the following:

- Cutting horsepower of the pump.
- Selected material
- Thickness of the material
- Types and quantity of holes
- Type of pierce
- Desired surface finish and tolerance.
- Number of parts in the stack (bundle)

Cutting time is computed for each geometric feature (simple holes, child edges of blanks, and complex holes).

Note: For pierce time, the machinability factor is based on the selected material. The factor is most closely related to material hardness and quantifies how easily the waterjet can pierce the material.

It is important to note that cutting speed is decreased as the nozzle approaches tight curves or sharp corners – particularly inside corners . If possible, your CAD design should fillet corners with the largest radius possible for best performance.

Cycle Time Calculations

**Overall Cycle Time = (Sum of cycle times for all features + Rapid Traverse Time)/
Number of parts in bundle**

Cycle time for the overall part (or part bundle) depends on the following:

- Individual feature cut times (see below)
- Rapid traverse time, which depends on the following:
 - Blank size
 - Machine's rapid traverse feed rate
- Bundle count (either computed, or specified by a user override)

**Individual Cycle Times = (Cut Time + Pierce Time [+ Corner Adjustment]) /
Machine Optimization Factor**

Cycle time for individual features (simple and complex holes, perimeters) depends on the following:

- Cut time, which depends on the following:
 - Cut time for small features
 - Cut time for large features
 - Cut time adjustment factor

Cut time depends on cut length and feed rate. Default feed rate depends on cut Quality (see the next paragraph) and part thickness, as well as waterjet pressure, water flow rate, abrasive flow rate, and mixing tube diameter. It also depends on whether the feature is large or small (see [Waterjet-Cut-specific Inputs](#)).

Cut Quality (see the previous paragraph) is assumed to be 2 for large features and 3 for small features. Quality 3 provides a good balance between speed, surface finish, corner compensation and precision. For straight line cutting, Quality of 3 cuts use the speed it would take to separate material that is three times as thick as the material being machined, with surface finish the same as the top one-third of a separation speed cut. For straight line cutting, Quality 2 cuts use the speed it would take to separate material that is twice as thick as the material being machined, with surface finish the same as the top half of a separation speed cut. A setup option allows the user to override the default feed rate--see [Waterjet-Cut-specific Inputs](#).

- Pierce time, which depends on the following:
 - Cross-section thickness
 - Machinability factor
- Corner Adjustment (for perimeter and complex hole cuts) which is computed based upon:
 - A plant variable specifying an adjustment factor
 - The number of sharp corners to cut
- Machine optimization factor
 - A machine variable used to distinguish between optimization software used by machine manufacturers.

Roll Bending (2-, 3-, and 4-roll)

aPriori uses the formulas below to determine costs associated with this bending process (used for plate rolling).

Expendable Tooling Cost -- unused

Setup Cost = (Setup Time per Part * Labor Rate) + (Setup Time per Part * Overhead Rate)

Labor Cost = Labor Rate * Labor Time / 3600 (seconds per hour)

Overhead Cost = (Labor Cost * Overhead Multiplier) + (Overhead Rate * Cycle Time / 3600)

Cycle Time Calculation (2-Roll Bending)

Cycle Time = Part Handling Time + Rolling Time

Cycle time for 2-Roll Bending is the product of the following:

- Rolling Time = (Arc Length) / (Machine Rolling Speed)
- Arc Length = Minimum Bend Radius * (Bend Arc Angle / DEGREES_PER_RADIAN)

Note: If yield strength reaches 90 % of ultimate tensile strength, then:

Rolling Speed = (Machine Rolling Speed) * (Plant Rolling Speed Adjustment Factor)

- Part Handling Time = load time + unload time

Note: Times are same as in Bend Brake.

Cycle Time Calculation (3- and 4-Roll Bending)

Cycle Time = Part Handling Time + (Rolling Time * Number of Passes) + Prebend Time

Cycle time for 3- and 4-Roll Bending is the product of the following:

- Rolling Time = (Part Cross-Section Sheet Width)/(Setup Rolling Speed)
- Rolling Speed = Machine Rolling Speed

Note: If yield strength reaches 90 % of ultimate tensile strength, then:

Rolling Speed = (Machine Rolling Speed) * (Plant Rolling Speed Adjustment Factor)

- Part Handling Time = load time + unload time (times same as in Bend Brake)
- Prebend Time = (2 * machine pre-bend)
- Number of passes: In 3- and 4-roll bending, some parts have to be rolled in multiple passes.

The component will be completed in one pass if:

Part Cross-Section Inside Diameter >= Machine property "Minimum Single Pass Diameter"

AND

Part Cross-Section Inside Diameter \leq Machine property “Minimum Multi Pass Diameter”

AND

Part Cross-Section Thickness \leq Machine property “Minimum Single Pass Thickness”

AND

Part Minimum Stock Length \leq Single Pass Roll Length

Single Pass Roll Length depends upon the Material Strength Ratio.

If Material Strength Ratio ≤ 1 , then

Single Pass Roll Length = (Machine Roll Working Length) *
(materialStrengthRatio) *

((Minimum Single Pass Diameter) / (Part Cross-section Inside Diameter))

If Material Strength Ratio > 1 , then

Single Pass Roll Length = (Machine Roll Working Length) *

((Minimum Single Pass Diameter) / (Part Cross-section Inside Diameter))

Material Strength Ratio = $\sqrt{(\text{Machine Reference Yield Strength}) / (\text{Material Tensile Yield Strength})}$

Note: Machine Maximum Working Length decreases when diameter increases and strength of material increases.

- Determining number of passes if greater > 1

The number of passes depends on the material springback, which increases with

- Higher yield strength
- High bend diameter to thickness ratio
- Bigger bend angle

Number of Passes = Material Strength Pass + Diameter Thickness Pass + Bend Angle Pass +
Additional Pass

where:

Material Strength Pass = +1 if (Material Yield Strength) $>$ Plant Reference Tensile Strength

Diameter Thickness Pass = + 2 (diameter to thickness was checked in the single pass rule above)

Bend Angle Pass = +1 (all tubes are 360 degrees, which is > 180)

Additional Pass = +1 if Part Thickness reaches 90% Machine Maximum Machine Thickness (to protect machine)

3D Laser

aPiori uses the formulas below to determine costs associated with these processes.

Accounting Calculations

Labor Time = Cycle Time * Number of Operators

Labor time is the product of the following

- Cycle time (see [Cycle Time Calculation](#))
- Machine labor time standard (specified as a machine property). This value reflects the amount of time spent by machine operators in between machine cycles, including time performing maintenance and cleaning tasks as well as time pausing between tasks. The amount is expressed as a cycle time multiplier.

Labor Cost = (Labor Time + 1 / 3600) * Machine Labor Rate

Labor cost is a function of the following:

- Labor time (see formula above)
- Machine labor rate (specified as a machine property)

Amortized Batch Setup = (Machine Setup Time * (Machine Labor Rate + Direct Overhead Rate)) / Batch Size

Amortized batch setup cost depends on the following:

- Machine setup time (specified as a machine property)
- Machine labor rate (specified as a machine property)
- Direct overhead rate (see [Direct and Indirect Overhead](#))
- Batch size (specified in the **Production Info** dialog)

Cycle Time Calculation

Cycle Time = Cut Time + Pierce

Cycle time depends on the following:

- Cut time, which is the product of the following:
 - Part perimeter (obtained from GCD extraction)
 - Laser feed rate (based on lookup in **sm3DLaserCutRate** by power requirement)
- Pierce time (based on lookup in **sm3DLaserCutRate** by power requirement)

Tolerance capability by hole diameter is contained in the lookup table **toleranceCapability**.

Cut-to-Length, Shear

aPiori uses the formulas below to determine costs associated with these processes.

Accounting Calculations

Labor Time = Cycle Time * Machine Labor Time Standard

Labor time is the product of the following

- Cycle time (see [Cycle Time Calculation](#))
- Machine labor time standard (specified as a machine property). This value reflects the amount of time spent by machine operators in between machine cycles, including time performing maintenance and cleaning tasks as well as time pausing between tasks. The amount is expressed as a cycle time multiplier.

Labor Cost = (Labor Time / 3600) * Machine Labor Rate

Labor cost is a function of the following:

- Labor time (see formula above)
- Machine labor rate (specified as a machine property)

Amortized Batch Setup = Machine Setup Time * Machine Labor Rate

Amortized batch setup is a function of the following:

- Machine setup time (specified as a machine property)
- Machine labor rate (specified as a machine property)

Cycle Time Calculation

Cycle Time = (1 / Machine Cut Speed) + Handling Time

Cycle time depends on the following:

- Machine cut speed
- Handling time (obtained from the lookup table `smShearHandling`, increases with part mass, which increases with material density)

Turret Press, Laser Punch, Plasma Punch

aPiori uses the formulas below to determine costs associated with this process.

Accounting Calculations

Labor Time = Cycle Time * Machine Labor Time Standard

Labor time is the product of the following

- Cycle time (see [Cycle Time Calculation](#))
- Machine labor time standard (specified as a machine property). This value reflects the amount of time spent by machine operators in between machine cycles, including time performing maintenance and cleaning tasks as well as time pausing between tasks. The amount is expressed as a cycle time multiplier.

Labor Cost = (Labor Time / 3600) * Machine Labor Rate

Labor cost is a function of the following:

- Labor time (see formula above)
- Machine labor rate (specified as a machine property)

Amortized Batch Setup = Machine Setup Time * Machine Labor Rate / Batch Size

Amortized batch setup is a function of the following:

- Machine setup time (specified as a machine property)
- Machine labor rate (specified as a machine property)
- Batch size (specified in the **Production Info** dialog)

Period Overhead = 0

Period overhead is always 0.

Cycle Time Calculation**Cycle Time = Punch Time + Nibble Time + Tool Change Time +
(Machine Labor Handling Time / Number of Parts Per Sheet)**

Cycle time depends on the following:

- Punch time
- Nibble time
- Tool change time (increases with increased variability in feature dimensions)
- Machine labor handling time (obtained from lookup by part mass in **smTurretPressHandling**)
- Number of parts per sheet (calculated based on part geometry, nesting type, and sheet dimensions)

Expendable Tooling**Expendable Tooling Cost = (Special Hole Tool Avg Cost * Small Special Tools) +
(Countersink Tool Avg Cost * Countersink Tools) +
(Form Tool Avg Cost * Form Tools) +
(Perforate Tool Avg Cost * Perforation Tools)**

Expendable tooling cost depends on the number and cost of the various types of tools.

User Inputs

The soft-tooled sheet metal processes provide the following process setup options:

- Top-level Process Setup
- Common Inputs
- Turret-Press-specific Inputs
- Waterjet-Cut-specific Inputs
- Plasma-Cut-specific Inputs
- Roll Bending Inputs
- Conical Roll Bending Inputs

Top-level Process Setup Options

The top-level Sheet Metal node provides the following options:

- Manufacturing Operation for Form Stamp GCDs
- Enable Scrap Material Credit
- Enable Scrap Part Credit

Manufacturing Operation for Form Stamp GCDs

Manufacturing Operation For Form Stamp GCDs: by default in starting point VPEs, the cost model assumes that small-depth features, such as indenting, lettering, or usage symbols, are created by a punching process, while larger-depth flats, pockets, and recesses are created by milling (in the Machining process group).

Administrators can change the default with the cost model variable **defaultManufacturingOperationForFormStampGCDs**. If this variable is set to **Punching**, Forms of type STAMP are created with punching operations, by default; if the variable is set to **Milling**, Forms of type STAMP are routed to secondary Machining and assigned milling operations, by default. In starting point VPEs, the variable is set to **Let aPriori Decide**.

With this setup option, you can override the default on a part-by-part basis. Specify one of the following:

- **Let aPriori Decide** (the default in starting point VPEs): a Form of type STAMP is created by a Sheet Metal punching process if its depth is less than the value of the cost model variable **maxStampingDepthThreshold** (0.3mm in starting point VPEs). Deeper STAMP Forms are routed to milling operations.
- **Punching:** all Forms of type STAMP are created by a Sheet Metal punching process.
- **Milling:** Forms of type STAMP are routed to secondary Machining and assigned milling operations.

Note that a feature assigned to milling may be assigned both roughing and finishing; if it is, a single tool is used for both.

Note that you can also manually include Chemical Milling in your routing, and STAMP Forms will be assigned to Chemical Milling.

Enable Scrap Material Credit

By default in starting point VPEs, the cost model assumes that material scrap (such as trim scrap) is *not* sold for credit. Administrators can customize the default with the cost model variable **enableScrapMaterialCredit** (**false** in starting point VPEs). With this setup option, users can override the default on a per-part basis.

Enabling scrap material credit increases material utilization and decreases material cost. The credit rate is specified as a percentage of the material rate by the material property **Scrap Cost Percent**. See [Formulas](#).

Enable Scrap Part Credit

By default in starting point VPEs, the cost model assumes that the material from scrapped parts is *not* sold for credit. Administrators can customize the default with the

cost model variable **enableScrapPartCredit** (**false** in starting point VPEs). With this setup option, users can override the default on a per-part basis.

Enabling scrap part credit increases material utilization and decreases material cost. This includes credit for parts scrapped by this process as well as by downstream processes. The credit rate is specified as a percentage of the material rate by the material property **Scrap Cost Percent**. See [Formulas](#).

Common Inputs

Note: these options are ignored if Hydroforming is the primary process group; use [Sheet Material Stock Options](#) in the Hydroforming process group, instead.

For Laser Cut, Laser Punch, OxyFuel Cut, Plasma Cut, Plasma Punch, Waterjet Cut, and Turret Press, you can define the following process setup options:

- **Part Orientation:** specifies whether the part's tightest bend (that is, the bend with the smallest radius) is parallel to or perpendicular with the sheet grain.
 - **Not Specified.** This is the default. aPriori selects the VPE's default orientation.
 - **Position Bend with Smallest Radius Parallel to Grain.** Bends are sometimes oriented parallel with the grain, for example, in order to minimize cracking.
 - **Position Bend with Smallest Radius Perpendicular to Grain.** Bends are sometimes oriented perpendicular to the grain, for example, to maximize strength.
- **Grain Direction:** specifies how the grain is oriented on the sheet. Grain can run parallel to the sheet's width or length. aPriori automatically selects the VPE's default grain direction. These options are provided:
 - **Parallel to Sheet Length**
 - **Parallel to Sheet Width**
- **Sheet Width Trim Strip—Margin along Material Width:** specifies the size of the margin along the width of the sheet. The margin is required to feed the sheet through the machine.
 - **Default value:** uses the VPE's default trim strip dimensions.
 - **User override:** user-specified margin in millimeters.
- **Sheet Length Trim Strip—Margin along Material Length:** specifies the size of the margin along the length of the sheet. The margin is required to feed the sheet through the machine.
 - **Default value:** uses the VPE's default trim strip dimensions.
 - **User override:** user-specified margin in millimeters.
- **Part Spacing (trim around the part) for True-Part Shape Nesting:** specifies the size of the margin around each part for true-part shape nesting.
 - **Default value:** uses the VPE's default part spacing.
 - **User override:** user-specified margin in millimeters.
- **Part Spacing (trim around the part) for Rectangular Nesting:** specifies the size of the margin around each part for rectangular nesting.
 - **Default value:** uses the VPE's default part spacing.
 - **User override:** user-specified margin in millimeters.

- **Step Angle for True-Part Shape Nesting:** specifies the part rotations aPriori considers in order to optimize nesting. aPriori considers non-negative, whole number multiples of this value that are less than 360 degrees.
 - **Default value:** uses default value of 90 degrees.
 - **User override:** user-specified value between 1 and 360 degrees.

When you use machining operations along with sheet metal processes, you can also define:

- **Part Tolerance Threshold**
- **Tool Material Preference**
- **Surface Roughness**
- **Virtual Tool Preference**
- **Setups**

Turret-Press-specific Inputs

Turret Press provides process-level setup options for specifying the total number of hits performed by the nibble, punch, and tapping operations. The Perforating operation provides setup options for specifying the total number of cluster and individual hits. There are also GCD-level setup options for controlling the number of hits performed to create a given feature.

Process-level Options

Turret Press provides the following process-level options :

- **Total Number of Punch Hits:** this is the number of total number of hits performed by the following operations:
 - Punching
 - Perforating
 - Countersinking
 - Lancing
 - Forming

By default, this is the sum of the total number of hits performed by each of these operations (see [Operation-level Options](#) and [GCD-level Options](#)). Enter a value to override the default.

- **Total Number of Nibble Hits:** this is the total number of hits performed by the Nibble operation. By default, this is the sum of the nibble hits required for each GCD that is created by Nibbling (see [GCD-level Options](#)). Enter a value to override the default.
- **Total Number of Tap Hits:** this is the total number of hits performed by the Tapping operation. By default, this is the sum of the tap hits required for each GCD on which Tapping is performed (see [GCD-level Options](#)). Enter a value to override the default.

Operation-level Options

The operation Perforating (performed on the Component GCD) provides the following setup options:

- **Cluster Hits:** this is the total number of cluster hits used to create the holes that are handled by the Perforating operation. A hole is handled by this operation if there are sufficiently many holes with the same size and shape, and sufficiently many nearby such holes (see [Operation-level Feasibility and Routing](#)). By default, the total number of cluster hits is the sum of the number of cluster hits required for each unique size-shape combination.

The number of cluster hits required to make all the holes of a given size and shape is the number required using the largest punch (from among 2X2-8X8 tools) that can make the holes using 2 or more cluster hits (together with 0 or more individual hits for “remainder” holes—see the option Individual Hits, below), under the assumption that the holes are arranged so as to allow optimal use of each punch.

In other words, the default number of cluster hits for a group of same-size/shape holes is the integer value of the result of dividing the number of holes in the group by the number of pins in the punch, using the largest punch for which this quotient is 2 or greater.

Enter a value for this option in order to override the default.

- **Individual Hits:** this is the total number of individual or “remainder” hits used to create the holes that are handled by the Perforating operation. A hole is handled by this operation if there are sufficiently many holes with the same size and shape, and sufficiently many nearby such holes (see [Operation-level Feasibility and Routing](#)). By default, the total number of individual hits is the sum of the number of individual hits required for each unique size-shape combination.

The number of individual hits required to make all the holes of a given size and shape is the number required using the largest punch (from among 2X2-8X8 tools) that can make the holes using 2 or more cluster hits (plus 0 or more individual hits), under the assumption that the holes are arranged so as to allow optimal use of each punch.

In other words, the default number of individual hits for a group of same-size/shape holes is the remainder of the result of dividing the number of holes in the group by the number of pins in the punch, using the largest punch for which this quotient is 2 or greater.

Enter a value for this option in order to override the default.

GCD-level Options

There are also setup options for controlling the number of hits performed to create a given GCD. The GCD-level options are provided for GCDs created by the following operations:

- Punching
- Nibbling

- Countersinking
- Flanging
- Forming
- Lancing
- Perforating
- Tapping

For all these operations except Punching and Nibbling, the default number of hits is 1.

For Punching a SimpleHole or a curved Edge of a Blank or ComplexHole, the default number of hits is 1. For Punching a straight Edge of a Blank or ComplexHole, the default number of hits depends on the following:

- Length of the Edge
- Maximum tool overlap, specified by the machine property **Max Tool Overlap**
- Candidate tool sizes, specified by the machine properties **Straight Length, 1** through **Straight Length, 5**

aPriori chooses the largest tool that will create the edge without excess overlap. The default number of hits is the edge length divided by the tool length, rounded up to the nearest integer:

Number of Punching Hits = roundup (Edge Length / Punching Tool Length)

For Nibbling a SimpleHole or the curved Edge of a Blank or ComplexHole, the default number of hits depends on the following:

- Circumference of the hole or length of the edge
- Nibble tool overlap. This is the fraction of the nibble tool diameter that should overlap the previously nibbled portion, specified by the machine property **Nibble Tool Overlap**.
- Nibble tool diameter (specified by the machine property **Nibble Tool Diameter**)

So the default number of hits is given by the following:

Number of Nibbling Hits = roundup (Hole Circumference or Edge Length / (Nibble Tool Diameter – (Nibble Tool Overlap * Nibble Tool Diameter)))

Enter a value to override the default.

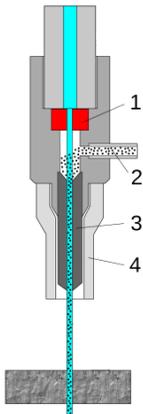
Waterjet-Cut-specific Inputs

The following user inputs apply specifically to the Waterjet Cut process:

- Number of Parts in Stack – Waterjet cutting supports stacking multiple parts if part thickness permits (maximum effective stack thickness is 12.7 mm). If stacking is not feasible, the default value is 1.0.
 - Default value
 - Computed value
 - User override

Note: As with other geometry-dependent PSO (Process Setup Option) settings, a value that is valid when you first enter it may be rendered invalid if you change the geometry at a later time. For example, you might have a component with a thickness of "5 mm" can have a valid stack value of "2". But if the height of the part is later changed to "10 mm", the stack value of "2" may no longer be valid, and costing operations may no longer succeed. aPriori checks the validity of these PSO settings only when they are first entered, and cannot re-evaluate them when geometry changes.

- Orifice Type (1)
 - Sapphire – (Default) Most common. Provides balance of cost (typically ` \$15 - \$30 each) and operating life (typically 50 to 100 cutting hours with good water quality; half that in abrasive applications).
 - Ruby – Similar to sapphire, but stream characteristics are suitable for abrasive cut, not for pure water.
 - Diamond -- Considerably longer run life (~16 – 20X) but is 10 to 20 times more expensive.. Suitable for 24-hour operation. Can sometimes be ultrasonically cleaned and reused



- Orifice Diameter (1) -- Default value determined from machine properties. Can be overridden with customer-specific value.
- Abrasive Flow Rate (2) -- Default value determined from machine properties. Can be overridden with customer-specific value. Abrasive flow rates represent a large portion of the total hourly cost (average cost of garnet is \$0.7275/kg), but the initial cost savings of reducing flow rate is outweighed by much greater costs of increased cutting time and increased replacement cost of expendable parts.
- Mixing Tube Diameter (3) -- Default value determined from machine properties. Can be overridden with customer-specific value.
- Nozzle Type (4)
 - Low-Cost Composite Carbide – Operating life 35 to 60 hours. Recommended for rough cutting or training.
 - Mid-Life Composite Carbide – (Default) Operating life 80 to 90 hours. Recommended for general purpose.
 - PremiumComposite Carbide -- Operating life 100 to 150 hours. Recommended for both precision and general purpose applications.

- **Feed Rate Small/Large Features** -- Default values determined from machine properties can be overridden with customer-specific values. A “feature” is part of the model. If a feature is “small” (see below) relative to the whole part, then cutting speed in this area is decreased. If a feature is “large” relative to the whole part, then the cutting speed in this area is increased.

A feature is determined to be “small” if:

- the ratio of a feature edge length to the part edge length is less than 0.01.
- the “minimum concave radius” is less than the “small Feature Feed Radius” (one of the machine parameters).
- the “minimum convex radius” is less than the “small Feature Feed Radius” (one of the machine parameters).
- the (diameter of hole)/2 is less than the “small Feature Feed Radius”.

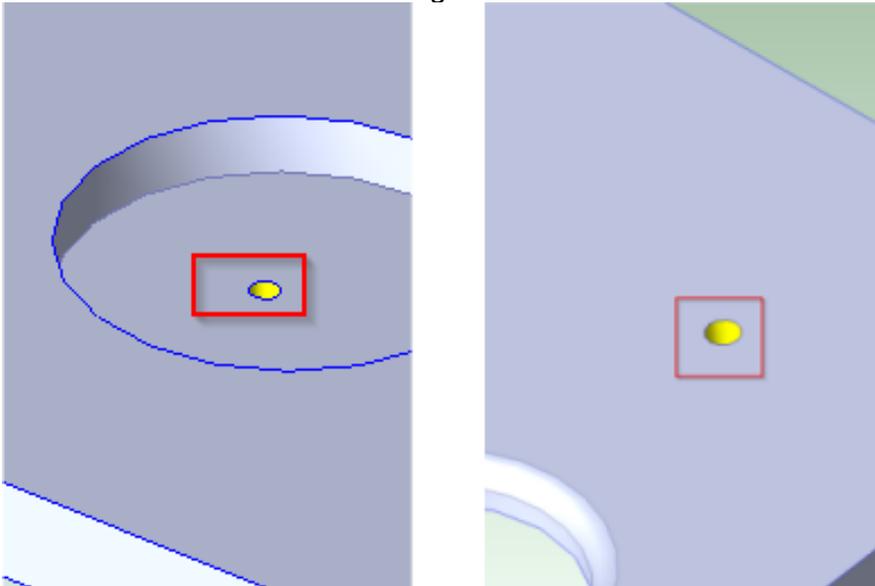
Any feature which is not determined to be “small” is treated as “large”.

A note about kerfs

Waterjet Cut can control the *kerf* -- or the width of the cut -- by swapping parts in the nozzle, as well as by changing the type and size of abrasive. Typical abrasive cuts have a kerf in the range of 0.04 in to 0.05 in, but can be as narrow as 0.02 in. Non-abrasive cuts are normally 0.007 in to 0.013 in, but can be as small as 0.003 in, which is approximately that of a human hair. These small jets can permit small details in a wide range of applications. Due to its relatively narrow kerf, water jet cutting can reduce the amount of scrap material produced, by allowing uncut parts to be nested more closely together than traditional cutting methods.

Why do two similar holes return different cycle times?

Consider the holes in the following illustration:



Both holes have a diameter of 7.32 mm and a length of 10.00 mm, yet Waterjet Cut cycle time for the hole on the left is 85 seconds, while the hole on the right takes only 19 seconds. This is actually correct, and here is why:

The simple hole on the left is contained within a pocket. The two are not concentric and are not considered a multistep hole, but the same logic applies if this was a multistep hole with a counterbore. The circular pocket cannot be made using waterjet because the feature does not extend the entire thickness of the part. (Only through-features can be made with waterjet.) So for this part, the blank perimeter and the simple hole are made using Waterjet Cut, but the pocket is machined. The length of that simple hole when made with Waterjet Cut depends on the order of operations. In most cases (especially when nesting), the blank and simple hole will be cut on the waterjet first and then transferred to a mill for the circular pocket. Since the pilot hole is created first, it is cut using the full thickness of the part and must run at a slower rate. The more rare case would be to machine the pocket first and then transfer to the waterjet. In that case, the material above the simple hole would already be removed and the waterjet could run at a faster rate, but again, this is a rare case.

Plasma-Cut-specific Inputs

The Plasma Cut process supports the following setup option:

- **Enable Plasma Bevel Cutting:** By default in starting point VPEs, chamfers are assumed to be created by secondary machining, so plasma bevel cutting is disabled. VPE administrators can customize the default with the cost model variable **defaultPlasmaBevelCuttingStatus** (**true** for enabled or **false** for disabled). Users can override the default on a part-by-part basis with this setup option.

Roll Bending Inputs

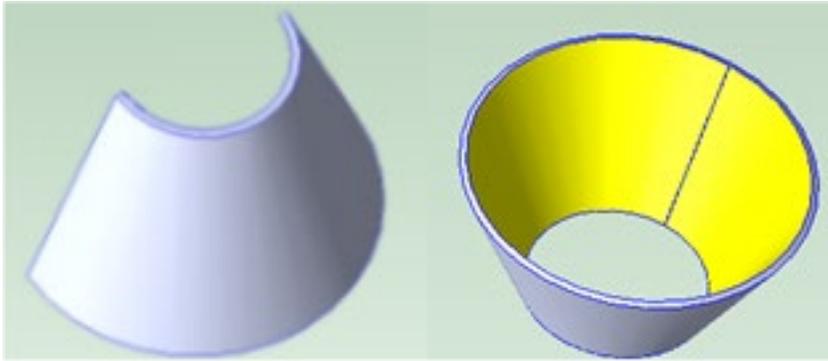
For **Roll Bending** (2-, 3-, or 4-roll) you can define the following process setup options:

- **Rolling speed** – The speed of the part through the machine, in mm/sec.
- **Total part handling time** – Load time plus unload time (plus re-roll handling time if applicable), in seconds).
- **Prebend time per edge** – Not applicable for 2-roll machines. The time in seconds to pre-bend the leading or trailing edge. For 4-roll machines only, both leading and trailing edges can be pre-bent in one operation.
- **Number of passes** – For 3- and 4-roll machines only, an integer specifying the number of passes required to generate the given bend.

Conical Roll Bending Inputs

You can manually assign 3- or 4-roll bending to conical geometry within the following guidelines:

- The cone must be a portion of a cone or a full cone with a slit.



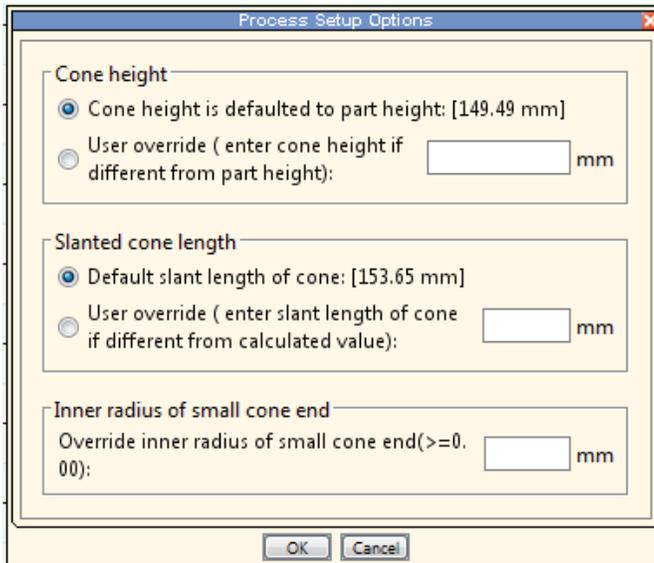
aPriori does not support 360 degree cones or cones without a small slit due to blank /sheet recognition

- aPriori does not definitively recognize a “Conical GCD”. Instead, the GCD is a Form with “Ruled” = true. The following screenshot shows an example of the Geometric Cost Driver panel for a conical part.

Geometric Cost Drivers				
Show ▾				
Status	Name	...	Name	Property Result
●	Component		Name	Form:1
●	Base Properties [1]		Area (mm^2)	192,454.79
●	Component:1		SER Length (mm)	1,236.77
●	Blank [1]		SER Width (mm)	359.70
	Main Surface [1]		Sub Type	EMBOSS
	Setup Axes/Candidates [5]		Depth Down (mm)	149.01
●	Bending/Forming		Depth Up (mm)	0.00
●	Forms [1]		Perimeter (mm)	2,803.86
● ●	Form:1		Length (mm)	-
	CurvedSurface:5		Bend Arc Angle (deg)	-
	CurvedSurface:6		Min Bend Radius (mm)	-
	CurvedSurface:7		Clock Angle (deg)	-
	CurvedSurface:8		Requested	3 Roll Bending
	GCD Relations		Selected	3 Roll Bending
	Intersects [1]		Status	●
	Is Accessible From [1]			

●	Bending/Forming		Roughness (µm)	<unspecified>
●	Forms [1]		Runout (mm)	<unspecified>
● ●	Form:1		Num Surfaces	1.00
	CurvedSurface:5		On Bounding Box	false
	CurvedSurface:6		Is on End	false
	CurvedSurface:7		Direction Type	Oblique
	CurvedSurface:8		Is Stock Surface	false
	GCD Relations		Approach From	NONE
	Intersects [1]		Approach From Alt	NONE
	Is Accessible From [1]		Ruled	true

- Various cone properties are estimated based on form dimensions, with PSOs provided to override defaults.



The image shows a dialog box titled "Process Setup Options" with a close button (X) in the top right corner. The dialog is divided into three sections, each with a title and two radio button options. The first section, "Cone height", has the first option selected: "Cone height is defaulted to part height: [149.49 mm]". The second option is "User override (enter cone height if different from part height):" followed by a text input field and "mm". The second section, "Slanted cone length", has the first option selected: "Default slant length of cone: [153.65 mm]". The second option is "User override (enter slant length of cone if different from calculated value):" followed by a text input field and "mm". The third section, "Inner radius of small cone end", has the text "Override inner radius of small cone end(>=0.00):" followed by a text input field and "mm". At the bottom of the dialog are "OK" and "Cancel" buttons.

Process Defaults and Thresholds

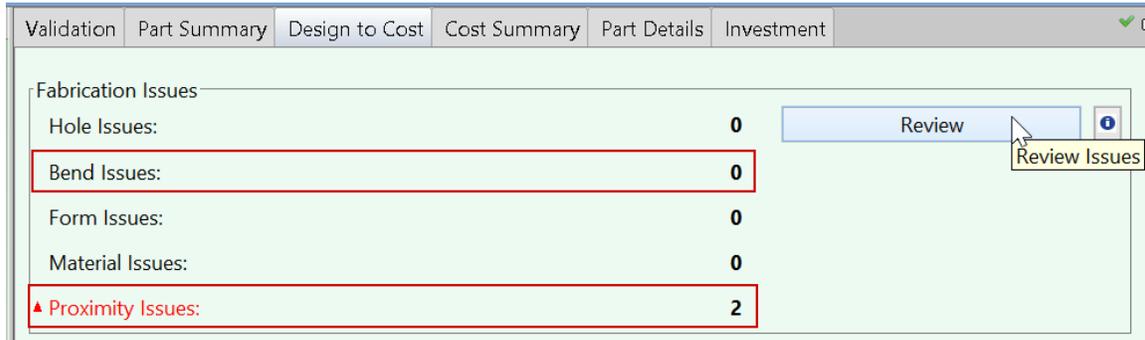
The table below lists some important plant variables. You can view all plant variables for a given process group within a specific VPE by using the following steps:

- 1 Select **Tools > VPE Toolset**, and then click the **VPE Manager** button in the **VPE Toolset** window.
- 2 Double click the desired VPE in the **Select VPE** window.
- 3 In the **VPE Manager**, click **+** to expand the **Sheet Metal** process group.
- 4 Under **Sheet Metal**, click **Variables**.

Variable Name	Description
defaultRectangularPartSpacing	Minimum space between parts when using rectangular nesting.
defaultUtilizationMethod	Eligible values: "COMPUTED" (rectangular), "TRUE_PART" & "MACHINE_DEFAULT"
enableScrapMaterialCredit	See Enable Scrap Material Credit .
enableScrapPartCredit	See Enable Scrap Part Credit .
minBendRadiusRatio	Factor to determine whether the bend radius is less than the recommended bend radius.
minStraightRadius	Minimum radius for a curve to be considered straight for the purpose of calculating laser cut feed rate. Feed rate is decreased for smaller radius curves; the maximum feed rate is used for straight sections.
waterjetAbrasiveCost	Cost of garnet abrasives for use in Waterjet Cutting. Used to calculate expendable tooling cost.
waterjetCornerAdjustmentFactor	Additional cycle time applied to account for the extra time required to stop the feed rate at each corner during Waterjet Cutting.
waterjetCutTimeAdjustmentFactor	Adjustment applied to Waterjet cut time to account for the extra time required for acceleration or deceleration to the required feed rate.
waterjetInsertCost	Cost of inserts for use in Waterjet Cutting. Used to calculate expendable tooling cost.
waterjetInsertLife	Life in hours of inserts for use in Waterjet Cutting. Used to calculate expendable tooling cost.
waterjetKerf	Kerf width for a Waterjet Cut part.
waterjetMaxMixingTubeDiameter	Maximum possible diameter of the waterjet mixing tube.
waterjetMaxOrificeDiameter	Maximum possible diameter of the waterjet jeweled orifice.
waterjetMaxPartThickness	Maximum part thickness for Waterjet Cutting. Waterjets can actually cut thicker parts but the cutting model breaks down above this threshold.
waterjetMinPartThickness	Minimum part thickness for Waterjet Cutting.
waterjetSmallEdgeThreshold	Ratio of individual edge segment length to total perimeter length below which an edge is considered small and must be cut using a slower feed rate.
waterjetWallThicknessToDepthRatio	Minimum allowable ratio of wall thickness to part thickness for a Waterjet Cut part.
waterjetAbrasiveCost	Cost of garnet abrasives for use in Waterjet Cutting. Used to calculate expendable tooling cost.

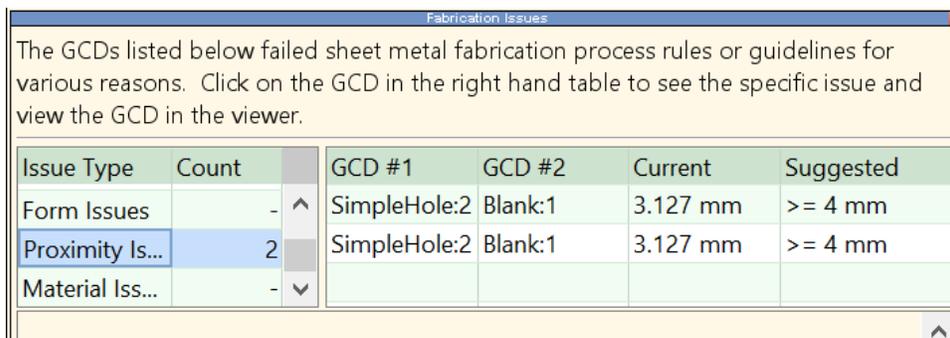
Design-to-cost Configuration for Sheet Metal

With the Sheet Metal process group, you can configure some of the thresholds that affect what is referenced as a **Proximity Issue** or **Bend Issue** in the Design to Cost tab.



A **Proximity Issue** arises when hole-creation feasibility is evaluated for a hole that is *too close* to another feature. The following sections cover cost model variables that control what counts as *too close*:

- Hole-to-bend Proximity Thresholds
- Hole-to-blank Proximity Thresholds
- Hole-to-form Proximity Thresholds
- Hole-to-hole Proximity Thresholds



One kind of **Bend Issue** occurs with the Bend Brake process, when the bend radius of a straight bend is *too small*. A cost model variable controls what counts as *too small*—see **Bend Issue Threshold**.

Hole-to-bend Proximity Thresholds

The cost model variables listed in the table below specify (for a given operation) the recommended minimum distance between a hole and a bend, expressed as a multiple of stock thickness. In starting point VPEs, the minimum recommended distance is 1.5 times the thickness of the stock, for all the listed operations. Anything closer is considered too close, and triggers a listing under Proximity Issues in the Design to Cost tab.

Operation(s)	Cost Model Variable
Laser Punching or Plasma Punching	combiPunchHoleToBendMultiplier
Laser Cutting	laserHoleToBendMultiplier
OxyFuel Cutting	oxyfuelHoleToBendMultiplier
Plasma Cutting	plasmaHoleToBendMultiplier
Perforating (Turret Press process)	turretPerforatingHoleToBendMultiplier
Punching (Turret Press process)	turretPunchHoleToBendMultiplier
Waterjet Cutting	waterjetHoleToBendMultiplier

Hole-to-blank Proximity Thresholds

The cost model variables listed in the table below specify (for a given operation) the recommended minimum distance between a hole and a blank edge, expressed as a multiple of stock thickness. In starting point VPEs, the minimum recommended distance is 1 times the thickness of the stock, for all the listed operations. Anything closer is considered too close, and triggers a listing under Proximity Issues in the Design to Cost tab.

Operation(s)	Cost Model Variable
Laser Punching or Plasma Punching	combiPunchHoleToBlankMultiplier
Laser Cutting	laserHoleToBlankMultiplier
OxyFuel Cutting	oxyfuelHoleToBlankMultiplier
Plasma Cutting	plasmaHoleToBlankMultiplier
Perforating (Turret Press process)	turretPerforatingHoleToBlankMultiplier
Punching (Turret Press process)	turretPunchHoleToBlankMultiplier
Waterjet Cutting	waterjetHoleToBlankMultiplier

Hole-to-form Proximity Thresholds

The cost model variables listed in the table below specify (for a given operation) the recommended minimum distance between a hole and a form, expressed as a multiple of stock thickness. In starting point VPEs, the minimum recommended distance is 1.5 times the thickness of the stock, for all the listed operations. Anything closer is considered too close, and triggers a listing under Proximity Issues in the Design to Cost tab.

Operation(s)	Cost Model Variable
Laser Punching or Plasma Punching	combiPunchHoleToFormMultiplier
Laser Cutting	laserHoleToFormMultiplier
OxyFuel Cutting	oxyfuelHoleToFormMultiplier
Plasma Cutting	plasmaHoleToFormMultiplier
Perforating (Turret Press process)	turretPerforatingHoleToBFormMultiplier

Punching (Turret Press process)	turretPunchHoleToFormMultiplier
Waterjet Cutting	waterjetHoleToFormMultiplier

Hole-to-hole Proximity Thresholds

The cost model variables listed in the table below specify (for a given operation) the recommended minimum distance between holes, expressed as a multiple of stock thickness. In starting point VPEs, the minimum recommended distance is 2 times the thickness of the stock, for all the listed operations. Anything closer is considered too close, and triggers a listing under Proximity Issues in the Design to Cost tab.

Operation(s)	Cost Model Variable
Laser Punching or Plasma Punching	combiPunchHoleToHoleMultiplier
Laser Cutting	laserHoleToHoleMultiplier
OxyFuel Cutting	oxyfuelHoleToHoleMultiplier
Plasma Cutting	plasmaHoleToHoleMultiplier
Perforating (Turret Press process)	turretPerforatingHoleToHoleMultiplier
Punching (Turret Press process)	turretPunchHoleToHoleMultiplier
Waterjet Cutting	waterjetHoleToHoleMultiplier

Bend Issue Threshold

The Bending operation (for the Bend Brake process) is feasible only for a StraightBend GCD whose **Min Bend Radius** is not too small. The cost model variable **minBendRadiusRatio** specifies the minimum feasible bend radius, as a multiple of stock thickness. In starting point VPEs, the minimum feasible bend diameter is 0.5 times the stock thickness. Anything smaller is considered too small, and triggers a listing under Bend Issues in the Design to Cost tab.

16 Sheet Metal— Stretch Forming

This chapter describes the costing details and inputs that are available for the Sheet Metal—Stretch Forming process group. This process group enables estimation of manufacturing times and costs for parts made with sheet stretch forming.

This chapter includes the following topics:

- Stretch Forming Overview
 - GCD Extraction for Stretch Forming
 - Routing for Stretch Forming
 - Machine Selection for Stretch Forming
 - Material Stock Selection for Stretch Forming
 - Formulas for Stretch Forming
 - User Inputs for Stretch Forming
 - Process Defaults and Thresholds for Stretch Forming
-

Stretch Forming Overview

This overview covers the following topics:

- Stretch Forming Processes
- Transverse and Longitudinal Stretch Forming
- Stretch Forming Geometry
- Stretch Forming Materials and Stock Forms
- Stretch Forming Machines
- Stretch Forming Tooling

Stretch Forming Processes

Stretch Forming routings include the following processes:

- 3-Roll Bending (from the Sheet Metal process group): stock is temporarily coiled in order to enable more efficient use of space during heat treatment and cold storage (see below).
- Solution (from the Heat Treatment process group): the coiled stock is annealed in order to decrease its tensile yield strength and ultimate tensile strength, in preparation for stretching.
- Cold Storage: the coiled stock is cooled in order to maintain the post-annealed material properties.
- Stretch Form: this process includes operations associated with the stretch forming machine, including cleaning and lubricating the tool, loading the blank onto the machine (and unloading it from the machine), inspecting the blank, pre-stretching it if necessary, and performing either transverse or longitudinal stretching (see [Transverse and Longitudinal Stretch Forming](#)).
- Shear (from the Sheet Metal process group): the formed part is trimmed in order to remove the addenda, which are added to the blank in order to provide material for the machine jaws to grip.
- Bench Operation: this process includes manual operations that are performed after the part is removed from the stretch forming machine. The operations are performed in a separate work area. They include cleaning and inspection, as well as hand forming of any curved bends.
- Router: near-net-shape trimming is performed using a hand router and a template.
- Machining: the part is routed to the 5-Axis Mill in the Machining process group for final-shape profile trimming (as well as hole creation, if necessary). Parts can also be manually routed to Chemical Milling for selective thickness reduction--in the Routing Selection dialog, expand the Machining node, and select Chemical Milling.

The sequence of processes consisting of Solution, Cold Storage, and Stretch Form can be performed one or more times before moving on to the Shear process. A setup option

controls the number of occurrences of the sequence on a part by part basis. A cost model variable controls the default number of occurrences (1 in starting point VPEs).

See [Routing for Stretch Forming](#) for more information.

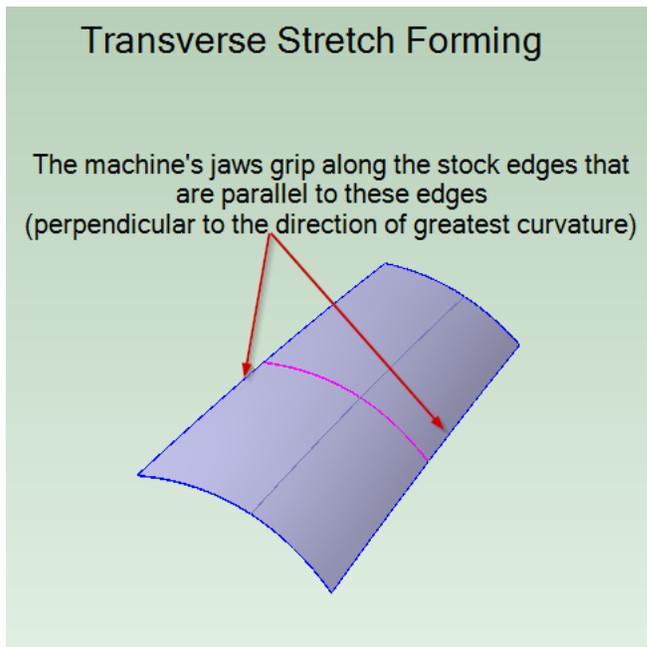
Transverse and Longitudinal Stretch Forming

For every stretch forming part, aPriori attempts to evaluate two different routings:

- *Transverse* stretch forming routing
- *Longitudinal* stretch forming routing

These routings correspond to two different types of stretch forming machines. The transverse routing involves the use of a transverse stretch forming machine, and the longitudinal routing involves the use of a longitudinal stretch forming machine.

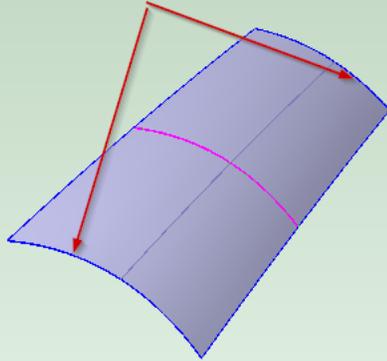
With a transverse machine, the jaws of the machine grip along the stock edges that are perpendicular to the direction of the part's greatest curvature.



With a longitudinal machine, the jaws grip along the stock edges that are parallel to the part's direction of greatest curvature.

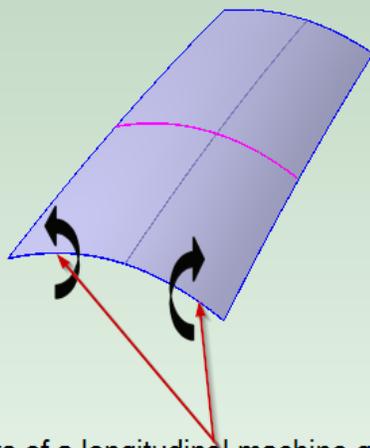
Longitudinal Stretch Forming

The machine's jaws grip along the stock edges that are parallel to these edges (parallel to the direction of greatest curvature)



The gripping jaws of a longitudinal machine (unlike those of a transverse machine) have a special rotational capability that aids in wrapping the blank around the tool. This capability is typically unnecessary with transverse stretching.

Longitudinal Stretch Forming



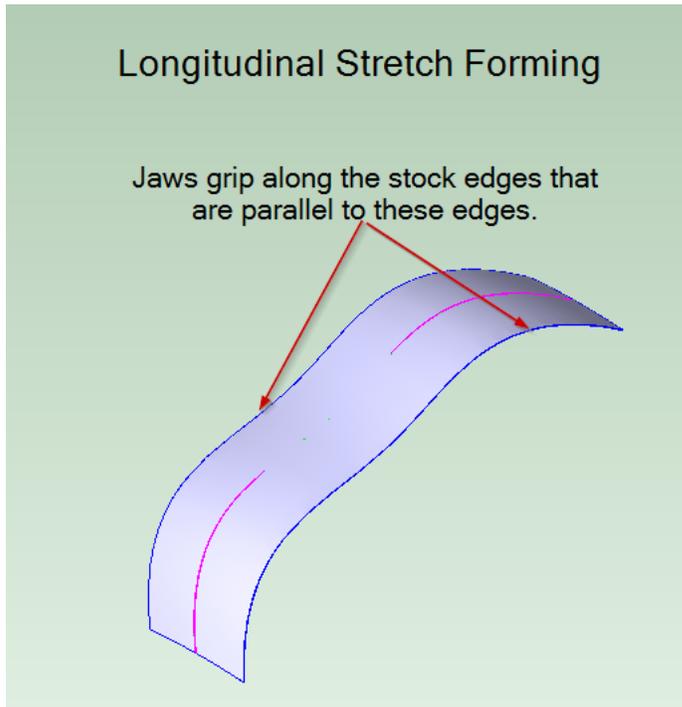
Jaws of a longitudinal machine grip the stock edges that are parallel to this edge. The jaws can rotate to aid in wrapping the blank around the tool.

For a given part, transverse and longitudinal stretch forming differ with regard to required pull force, and the required stock addenda, among other factors that affect cost.

Transverse stretching is generally preferred, but in some cases it is not practical. For example, transverse stretch forming is sometimes infeasible when the blank edges perpendicular to the direction of greatest curvature are very long. The length of these

edges may exceed the greatest length along which the jaws can grip, for any stretch forming machine. In such a case, the solution is to use a machine that can grip the shorter edges, which in this case are the edges parallel to the curvature direction. In other words, the solution in this case is to use a longitudinal machine.

Transverse stretch forming is also sometimes infeasible when the part's concavity is not sufficiently consistent along the direction of greatest curvature. The part shown below requires longitudinal stretch forming.



See [Process Feasibility for Stretch Forming](#) and [Stretch Form Machine Selection](#) for more information about process and machine feasibility.

When both transverse and longitudinal stretching are feasible for a given part, aPriori costs both approaches and determines which is less expensive. (The cost model does not support scenarios that require both transverse and longitudinal stretching on the same part.)

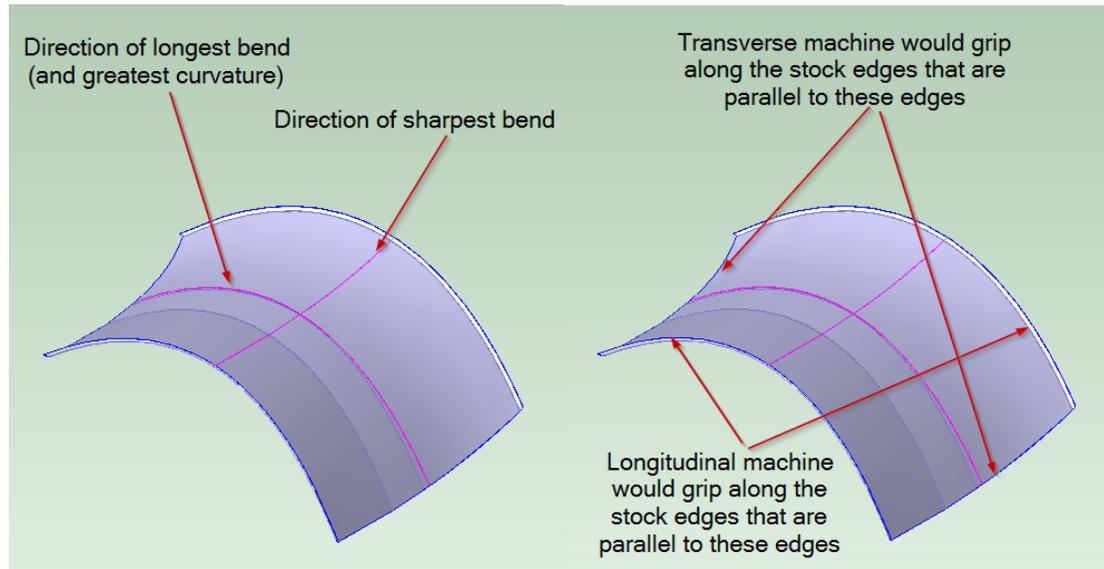
It is important to note that the Stretch Forming cost model distinguishes between direction of greatest curvature and direction of sharpest bend (smallest radius of curvature). The direction of sharpest bend is *often* the direction of greatest curvature, but there are cases in which it is not. This is because the cost model considers degree of curvature in a given direction to have two components:

- Sharpness of the bend in the given direction (the reciprocal of the radius of curvature)
- Length of the bend in the given direction

Consider for example a saddle-shaped part. Such a part might have bends of similar sharpness along two, orthogonal directions; and the bend in one direction might be significantly longer than the bend in the other direction. In such a case, the cost model evaluates both the direction of sharpest bend and the direction orthogonal to it, and

combines considerations of sharpness and length. (The cost model uses *curve height* as a reflection of a combination of sharpness and length. See [Xsection GCDs](#) and [Xsection Curve Height for Stretch Forming](#) for more information.)

For the part below, the direction of greatest curvature, in this sense, is along the part's length, even though the direction of sharpest bend is along its width. So a transverse machine would grip the edges along the stock's width, and a longitudinal machine would grip the edges along the stock's length.



Stretch Forming Geometry

Following are some of the important GCD types identified by geometry extraction for the Stretch Forming process group:

- **Blank:** as with other sheet metal process groups, there is a single Blank GCD that represents the flattened part. The flattening calculation uses a finite element analysis derived from the part's CAD model and the properties of the selected material. (Note that if you change the selected material and re-cost, you must be CAD-connected, since flattening must be re-calculated and geometry re-extracted.) See [Blank GCD](#) for more information.
- **Forms:** extracted GCDs include three types of Form GCD (which differ with regard to the **Sub Type** property):
 - EMBOSS forms (created by the Stretch Form process)
 - CURVED_BEND forms (assumed to be hand formed)
 - STAMP forms (areas of thickness reduction that are assigned to chemical milling, when the Chemical Milling process routing is manually selected)
- **Ram Direction:** in the Stretch Forming process group, this GCD represents a candidate for the direction from which the ram approaches the stock during the stretch forming process. In some cases (for example, for some saddle-shaped parts), the direction that is the opposite of the ram direction is also a candidate for the direction from which the ram approaches. See [Ram Direction GCD](#) for more information.

- **Xsection:** there are two Xsection GCDs that represent cross-sections of the part. One Xsection is aligned with the direction of least sharp bend, and the other Xsection is orthogonal to it. The properties of the Xsections help the cost model determine feasible stretching directions for the part, as well as the required pull force. See [Xsection GCDs](#) for more information.

Stretch Forming Materials and Stock Forms

Supported Material types for the Stretch Forming cost model include aluminum and stainless steel alloys.

If you change the material selection for a given part and re-cost, you must be CAD-connected so that the part's flat outline can be recalculated and geometry re-extracted. See [Blank GCD](#) for more information.

The Stretch Forming cost model selects sheet stock for a part based on the following:

- Blank thickness
- Length and width of the stretch-direction-aligned bounding box of the part
- Length and width addendum values, specified by cost model variables

See [Material Stock Selection for Stretch Forming](#) for more information.

Stretch Forming Machines

Starting point VPE machines for the Stretch Form process include actual and virtual machines that perform either transverse stretching or longitudinal stretching. There are also some actual machines that have both transverse and longitudinal pull capability. The machines with transverse pull capability include both simple and tangential machines.

Actual machines include Cyril-Bath, Erco, Fritz Muller, MFBA, and Sheridan

Virtual machines include machines of the following types:

- Small, medium, and large, simple, transverse stretching machines
- Small, medium, and large, tangential, transverse stretching machines
- Small, medium, and large, tangential, longitudinal stretching machines

See [Machine Selection for Stretch Forming](#) for more information.

Stretch Forming Tooling

The following Stretch Forming processes employ hard tooling:

- Stretch Form
- Bench Operation (for manual forming)
- Router

Tooling costs for each process can be specified with setup options. See [Setup Options for Stretch Forming Cycles](#), [Setup Options for Bench Operation](#), and [Setup Options for Router](#).

For both Stretch Form and Router, the default tooling cost is the product of three factors:

- Cost per unit area: specified by the following cost model variables:
 - For Stretch Form: **defaultStretchFormToolingCost** (\$23250/m² in starting point VPEs)
 - For Router: **defaultRouterJigToolingCost** (\$4420/m² in starting point VPEs)
- Total area of the part's forms of type EMBOSS.
- Region multiplier: adjusts for regional price variance. Specified by the cost model variable **regionMultiplier**.

For the Manual Forming operation of the Bench Operation process, the default tooling cost in starting point VPEs is 20% of the Stretch Form tooling cost. In general, it is the product of the following:

- Stretch Form tooling cost (see above)
- Adjustment factor: specified by the cost model variable **defaultManualFormingToolingMultiplier** (0.2 in starting point VPEs)

By default, tooling cost calculations assume that a single tool lasts long enough to produce the production volume specified in any scenario. VPE administrators can customize the default number of tools assumed for the current production scenario. Users can override the default on a per-part basis and specify the number of tools. The cost model accounts for the specified number of tools in total hard tooling cost.

For more information, see the following:

- [Number of Forming Block Tools Required](#) (for Hydroform Cycles)
- [Number of Counter Form Tools](#) (for Hydroform Cycles)
- [Number of Tools Required](#) (for Bench Operation)
- [Number of Tools Required](#) (for Router)

For a given costing, either the formula Dependencies or Investment tab displays the number of tools assumed by tooling cost calculations.

GCD Extraction for Stretch Forming

Following are some of the important GCD types for Stretch Forming:

- Blank GCD
- Xsection GCDs
- Ram Direction GCD
- Form GCDs

Blank GCD

The Blank GCD is specific to the Sheet Metal process groups. It represents the flattened part. Its properties (such as **Perimeter**, **Thickness**, **SER Length**, and **SER Width**) are listed in the Geometric Cost Drivers pane.

aPriori determines the outline of the flattened part based on a forming simulation which uses a finite element analysis derived from the part's CAD model and the properties of the selected material.

When you select the Blank GCD in the Geometric Cost Drivers pane, the Viewer displays the following:

- Blank outline in pink
- Blank SER in yellow: this is the smallest-area rectangle that encloses the blank.

You can display the flat pattern head on, in a separate window, together with its associated SER, by selecting **Flat Outline** from the Analysis menu in the Viewer toolbar.

As mentioned above, determination of the flattened outline takes into account material properties, including the following:

- Density
- Young's Modulus
- Poisson's Ratio, K (strain-hardening coefficient)
- N (strain-hardening exponent)
- R (Lankford parameter, average).

Materials in starting point VPEs specify these properties. If your VPE includes a material that doesn't specify these properties, aPriori uses the following default values based on material type:

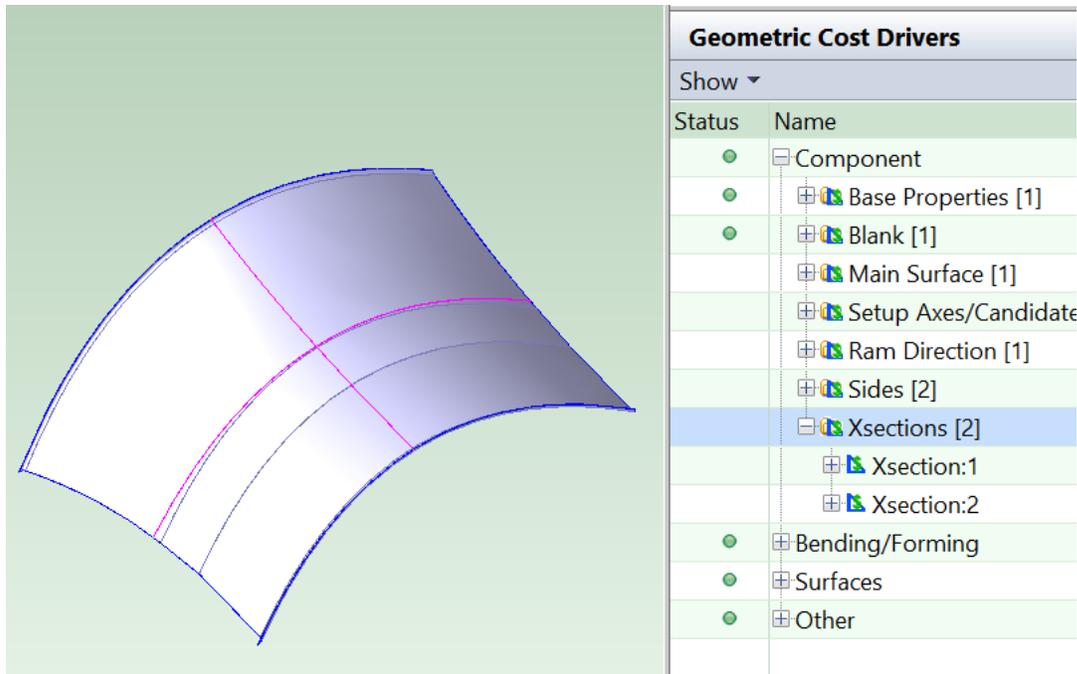
Material Type	Young's Modulus (MPa)	Poisson Ratio	K (strain-hardening coefficient, MPa)	N (strain-hardening exponent, MPa)	R (Lankford parameter, average)
Aluminum	69000	0.33	341.1	0.21	0.7
Copper	115000	0.33	317	0.54	0.99
Galvanized Steel	207000	0.28	543	0.21	0.99
Stainless Steel	207000	0.28	1426	0.502	1
Steel	207000	0.28	0.28	479.3	1.345

If the material type is not one listed in the table above, the entries for Steel are used.

Note that if you change the material selection for a given part and re-cost, you must be CAD-connected so that the part's flat outline can be recalculated and geometry re-extracted.

Xsection GCDs

Geometry extraction for the Stretch Forming process group extracts two special GCDs that represent cross-sections of the part. These are listed as Xsection GCDs in the Geometric Cost Drivers pane, and are displayed in the Viewer in purple.



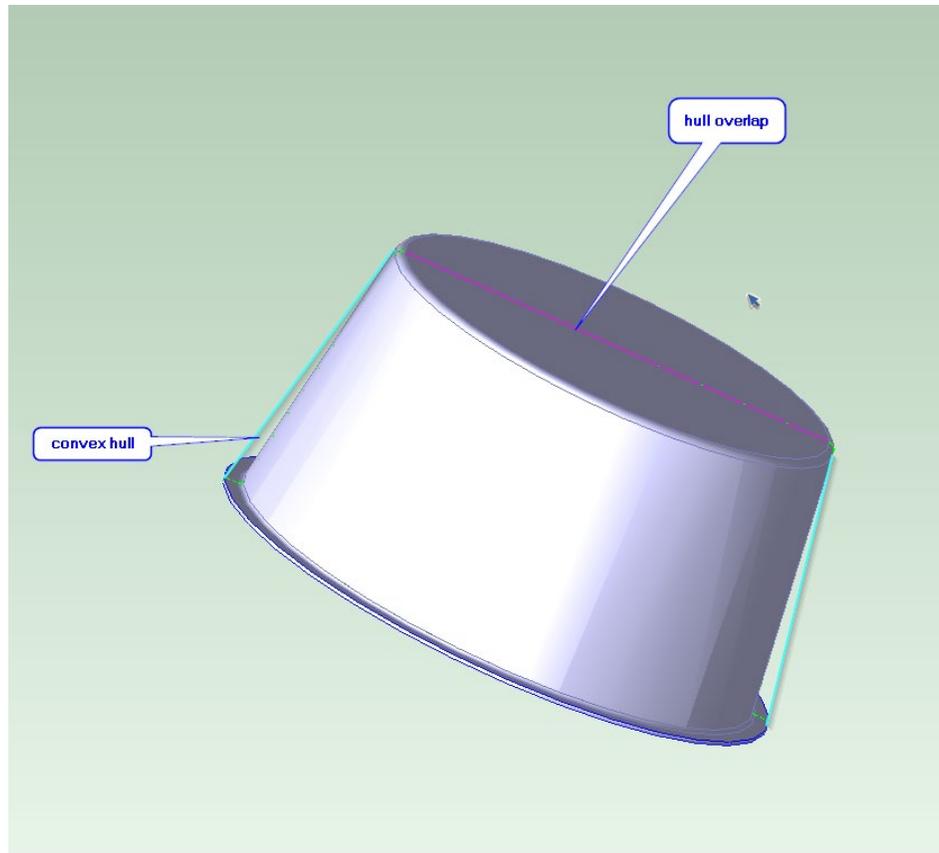
The properties of Xsection GCDs help the cost model determine feasible stretching directions for the part, as well as the required pull force (see [Stretch Form Process Feasibility and Required Pull Force for Stretch Forming](#)).

Both Xsections are positioned based on a heuristic designed to avoid locating them so that they cross cutouts in the blank. In the absence of cutouts, both Xsections pass through the middle of the blank's SER.

One Xsection is aligned with the direction of maximum radius of curvature, and the other Xsection is orthogonal to it. (If there is no unique direction of maximum radius of curvature—as with, for example, a portion of a sphere—then the Xsections are aligned with the blank's SER length and width.)

Many of the important Xsection properties are defined in terms of the following geometric objects associated with each Xsection (these objects are not explicitly represented as GCDs):

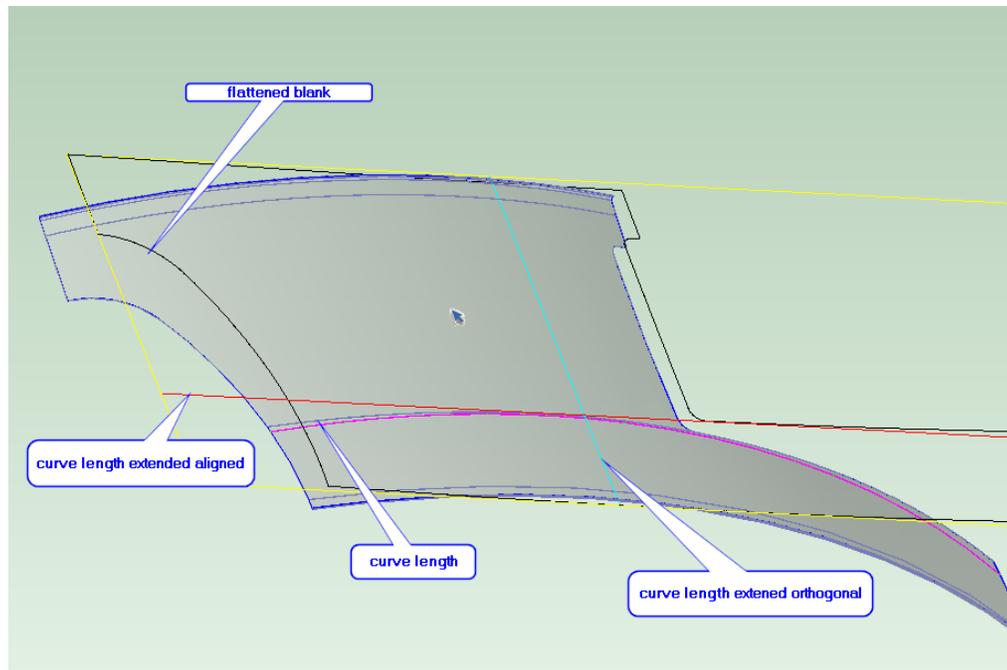
- Xsection curve: the intersection of the Xsection with the surface of the part
- Xsection hull: the shape described by a string aligned with the Xsection curve and tightened around one side of the part (the side that results in the longest hull overlap—see below).
- Xsection hull overlap: portion of the Xsection hull that is in contact with the Xsection curve. Note that the overlap might consist of multiple, non-contiguous segments of the hull.



Following are some of the important Xsection properties:

- Hull Overlap Length: total length of the Xsection hull overlap.
- Hull Avg Curvature: reciprocal of the average radius of curvature of the hull overlap (that is, average radius of curvature of the portion of the Xsection hull that is in contact with the Xsection curve).
- Hull Min Curvature: reciprocal of the radius of curvature of the flattest point of the hull overlap. If there is a completely flat segment of the overlap (that is, if the overlap crosses a plane), this value is set to 0.
- Hull Max Curvature: reciprocal of the radius of curvature of the sharpest point of the hull overlap. For sharp corners, this value is set to 2 divided the part thickness.
- Hull direction: this is **UP** when the direction from the hull to the chord connecting its endpoints is the ram direction. This is **DOWN** when the direction from the hull to the chord connecting its endpoints is the opposite of the ram direction.
- Curve Length: length of the Xsection curve
- Curve Length Extended Aligned: distance, in the direction of the Xsection, across the Xsection-aligned bounding box of the flattened blank
- Curve Length Extended Orthogonal: distance, in the direction orthogonal to the Xsection, across the Xsection-aligned bounding box of the flattened blank

- Rectangle Lower Left and Rectangle Upper Right: these provide coordinates of opposite corners of the smallest enclosing rectangle of the Xsection curve. The coordinates use a coordinate system whose origin is the intersection of the two Xsections and whose y-axis is tangent to the Xsection curve at the origin.



Ram Direction GCD

In the Stretch Forming process group, this GCD represents a candidate for the direction from which the ram approaches the stock during the stretch forming process. For some parts (for example, saddle-shaped parts) the direction from which the ram approaches for transverse stretching is one direction, while the direction from which the ram approaches for longitudinal stretching is the opposite direction. So both the ram direction and its opposite are candidate approach directions (though only one is explicitly represented as a GCD).

aPriori chooses the ram direction as described in [How the Default Ram Direction is Chosen](#) in the Sheet Metal—Transfer Die chapter of this *Guide*.

When you select the GCD in the Geometric Cost Drivers pane, the ram direction is displayed as an arrow. You can manually override the ram direction if necessary. See [Overriding the Default Ram Direction](#) in the Sheet Metal—Transfer Die chapter.

Form GCDs

Extracted GCDs include three types of Form GCD (which differ with regard to the **Sub Type** property):

- **EMBOSS**: these are created by the Stretch Form process. If there is more than one EMBOSS form, one is chosen as the primary form and is assigned to the Stretch Forming operation; all other forms are assumed to be created by this operation as well, though they are not explicitly assigned to it.

- **CURVED_BEND**: these GCDs are assumed to be hand formed. They are created by the Bench Operation process, and assigned to the Manual Forming operation.
- **STAMP**: on Stretch Forming parts, these represent areas of thickness reduction that are assigned to chemical milling, when the Chemical Milling process routing is manually selected.

Routing for Stretch Forming

The Stretch Forming cost model supports two process-level routings:

- One that includes transverse stretching
- One that includes longitudinal stretching

The transverse routing includes an operation that stretches the part along the Xsection (see [Xsection GCDs](#)) that has the greater curve height (of the two Xsections). The longitudinal routing includes an operation that stretches the part along the Xsection that has the smaller curve height (see [Xsection Curve Height for Stretch Forming](#)).

To cost the part, aPiori chooses the lowest-cost, feasible routing for which there is a feasible stretch forming machine (see [Process Feasibility for Stretch Forming and Stretch Form Machine Selection](#)).

The routings differ only with regard to which process-level operation the Stretch Form process applies: either Stretch Form—Transverse or Stretch Form—Longitudinal. The routings include the following processes:

- **3-Roll Bending**: this process, from the Sheet Metal process group, defines the Coil Uncoil operation on the Component GCD, which accounts for the cost of coiling the blank before heat treatment, as well as the cost of uncoiling it after cold storage.
- One or more stretch form cycles, each of which consists of the following Processes:
 - **Solution**: from the Heat Treatment process group, accounts for the cost of annealing the coiled part in preparation for stretching. The material properties **Tensile Yield Strength** and **Ultimate Tensile Strength** are pre-annealed properties, while **Annealed Tensile Yield Strength** and **Annealed Ultimate Tensile Strength** are post-annealed properties.
 - **Cold Storage**: accounts for the cost of cooling the coiled stock in order to maintain the post-annealed material properties.
 - **Stretch Form**: this process applies a component-level operation for either transverse or longitudinal stretch forming (Stretch Form--Transverse or Stretch Form—Longitudinal). The component-level operation, in turn, applies a number of operations associated with the stretch forming machine—see below.

The cost model variable **defaultNumStretches** controls the default number of cycles (1 in starting point VPEs). The setup option **Number of Stretch Form Cycles** controls the number of cycles on a part by part basis. See [Setup Options for Stretch Forming Cycles](#).

Manufacturing Process	
Edit	Primary Process Group: Sheet Metal - St
Status	Process Step
●	Sheet Metal - Stretch Form
●	Material Stock
●	3 Roll Bending
●	Stretch Form Cycles [3]
●	Stretch Form Cycle
●	Solution
●	Cold Storage
●	Stretch Form [1]
●	Stretch Form Cycle:2
●	Solution:2
●	Cold Storage:2
●	Stretch Form:2 [1]
●	Stretch Form Cycle:3
●	Solution:3
●	Cold Storage:3
●	Stretch Form:3 [1]
●	Shear
●	Bench Operation
●	Router
●	Machining

- Shear: from the Sheet Metal process group, this process accounts for the cost of trimming the formed part in order to remove the addenda, which are added to the blank in order to provide material for the machine jaws to grip. See [Material Stock Selection for Stretch Forming](#).
- Bench Operation: this process defines operations for cleaning and inspection of the formed part, and for hand forming of Form GCDs of type **CURVED_BEND**.
- Router: this process accounts for the cost of performing near-net-shape trimming using a hand router and a template.
- Machining: the part is routed to 5-Axis Mill in the Machining process group, which accounts for the cost of final-shape profile trimming (as well as hole creation, if necessary). Parts can also be manually routed to Chemical Milling. (In the Routing Selection dialog, expand the Machining node, and select Chemical Milling; with this process routing selected, forms of type **STAMP** are automatically assigned to chemical milling.)

Transverse or Longitudinal Stretch Forming applies the following child operations:

- Inspecting: blank inspection.
- Loading: blank loading onto the stretch forming machine.
- Pre-stretching: optional operation, included only when a tangential stretch forming machine is selected, that is when the machine property **Process Type** is **Tangential**.

- Stretch Forming: performed on form of type EMBOSS. If there is more than one EMBOSS form, one is chosen as the primary form and is assigned to the Stretch Forming operation; all other forms of type EMOBOSS are assumed to be created by this operation as well.
- Tool Cleaning: tool cleaning in between stretches.
- Tool Lubricating: tool lubricating in between stretches.
- Unloading: blank unloading from the stretch forming machine.

Process Feasibility for Stretch Forming

Process feasibility for Stretch Forming is covered in the following sections:

- Stretch Form Process Feasibility
- Xsection Curve Height for Stretch Forming

Stretch Form Process Feasibility

In order to evaluate Stretch Form feasibility, the cost model first determines which of the two Xsection GCDs (see *Xsection GCDs*) has the greater *curve height* (see *Xsection Curve Height for Stretch Forming*). The Xsection with the greater curve height is referred to as the *transverse* Xsection; the other Xsection is referred to as the *longitudinal* Xsection.

The cost model always evaluates the feasibility of both the transverse routing and the longitudinal routing (see *Routing for Stretch Forming*).

Transverse stretching is feasible if a sufficient fraction of the transverse Xsection curve is in contact with its associated hull. Similarly, longitudinal stretching is feasible if a sufficient fraction of the longitudinal Xsection curve is in contact with its associated hull (see *Xsection GCDs*).

A sufficient fraction of the curve is in contact with the hull if the ratio of the GCD property **Hull Overlap Length** to the GCD property **Curve Length** is less than or equal to the cost model variable **allowableHullToCurveRatio** (0.8 in starting point VPEs):

- $\text{Hull Overlap Length} / \text{Curve Length} > \text{allowableHullToCurveRatio}$

Xsection Curve Height for Stretch Forming

Xsection curve height (used to identify the transverse and longitudinal Xsections—see *Stretch Form Process Feasibility*) is estimated in one of two ways:

- Based on the Xsection properties **Rectangle Upper Right** and **Rectangle Lower Left**.
- Based on the Xsection properties **Hull Avg Curvature** and **Curve Length Extended Aligned**.

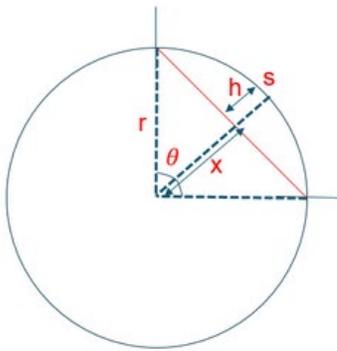
The curve height is usually estimated as the difference between the x components of the Xsection properties **Rectangle Upper Right** and **Rectangle Lower Left**. The accuracy of this method of estimation can suffer when an Xsection ends at a cutout. In some such cases, this method yields a smaller height than the height of parallel cross-sections that avoid the cutout.

If the Xsection hull is close to being a circular arc, aPriori uses a different, trigonometric method (described below) that provides an accurate estimate. If the Xsection ends at a cutout and the hull is *not* close to being an arc, aPriori may underestimate the curve height.

The Xsection hull is considered close to being a circular arc if **Hull Max Curvature** is no more than 20% greater than **Hull Average Curvature**.

Note that among the cases in which the hull is not close to being an arc are cases in which the Xsection intersects a flange on the part.

With the trigonometric method, the cost model treats the Xsection hull as an arc of a circle whose radius is $1/\text{Hull Avg Curvature}$, where the length of the arc is **Curve Length Extended Aligned**. The curve height (h in the diagram below) is calculated as the distance along a radius from the arc to the midpoint of the chord connecting the arc endpoints:



Curve Height = Radius – Distance from Center to Chord

Curve height (h in the diagram) is the difference between the following:

- Radius: r in the diagram. This is the reciprocal of **Hull Avg Curvature**.
- Distance from center to chord: x in the diagram. See formula.

Distance from Center to Chord = Radius * $\cos(\theta/2)$

This is x in the diagram. It is the distance from the center of the circle (of which the hull is an arc) to the chord midpoint. The distance depends on the following:

- Radius: r in the diagram. This is the reciprocal of **Hull Avg Curvature**.
- θ : angle subtended by the arc. See formula.

$\theta = \text{Curve Length Extended Aligned} / \text{Radius}$

This is the angle in radians subtended by the arc. It is the quotient of the following:

- Curve length extended aligned: s in the diagram. This is specified by the Xsection property **Curve Length Extended Aligned**.
- Radius: r in the diagram. This is the reciprocal of **Hull Avg Curvature**.

Machine Selection for Stretch Forming

Machine selection for Stretch Forming is covered in the following sections:

- Cold Storage Machine Selection
- Stretch Form Machine Selection
- Bench Operation Machine Selection
- Router Machine Selection

Cold Storage Machine Selection

For the Cold Storage process, the cost model selects the feasible machine with the smallest length (specified by the machine property **Usable Length**).

If the part uses a single stretch cycle, the stock is assumed to be coiled before annealing and cooling (see [Routing for Stretch Forming](#)). In this case, a machine is considered feasible if it can accommodate the dimensions of the coiled stock (with the stock oriented so that its width dimension is perpendicular to the ceiling). In particular, the machine is feasible if both the following hold:

- Machine property **Usable Height** is greater than the coil height (which is the stock width).
- Machine properties **Usable Length** and **Usable Width** are both greater than the coil diameter (specified by the Sheet Metal cost model variable **defaultCoilDiameter** (300mm in starting point VPEs)).

If the part uses multiple stretch cycles (see [Number of Stretch Form Cycles](#)), the stock is assumed to be uncoiled. In this case, a machine is considered feasible if it can accommodate the dimensions of the selected stock (with the stock oriented so that its width dimension is perpendicular to the ceiling). In particular, the machine is feasible if both the following hold:

- Machine property **Usable Height** is greater than or equal to the stock width.
- Machine property **Usable Length** is greater than the stock length.

See [Material Stock Selection for Stretch Forming](#) for information about stock length and width.

Note that aPriori selects only from preferred machines, if there is a feasible preferred machine and the cost model variable **usePreferredMachines** is set to **true** (the default in starting point VPEs). If there is no feasible preferred machine, or if the cost model variable **usePreferredMachines** is set to **false**, aPriori selects from all machines. A machine is preferred if the machine property **isPreferred** (typically displayed as **Is Preferred**) is **true**.

Stretch Form Machine Selection

For the transverse stretch forming routing, the cost model selects the lowest-overhead, feasible machine that has transverse pull capability (see [Machine Feasibility for Stretch Forming](#)).

For the longitudinal stretch forming routing, the cost model selects the lowest-overhead, feasible machine that has longitudinal pull capability (see [Machine Feasibility for Stretch Forming](#)).

Overhead is the sum of the machine properties **Direct Overhead Rate** and **Indirect Overhead Rate**.

Note that aPiori selects only from preferred machines, if there is a feasible preferred machine and the cost model variable **usePreferredMachines** is set to **true** (the default in starting point VPEs). If there is no feasible preferred machine, or if the cost model variable **usePreferredMachines** is set to **false**, aPiori selects from all machines. A machine is preferred if the machine property **isPreferred** (typically displayed as **Is Preferred**) is **true**.

See the following sections for more information:

- [Machine Feasibility for Stretch Forming](#)
- [Required Pull Force for Stretch Forming](#)

Machine Feasibility for Stretch Forming

A machine has transverse pull capability if the machine property **Transverse Pull Capability** is **true**. Such a machine is feasible if it can accommodate the dimensions of the blank and can provide the required pull force; that is, a transverse machine is feasible if all the following hold:

- **Required pull force:** the pull force required for the part does not exceed the machine's pull force capability (specified by the machine property **Press Force**). The required pull force, for a part and a given material, is proportional to the area of the Xsection orthogonal to the pull direction. See [Required Pull Force for Stretch Forming](#) for more information.
- **Required length:** transverse Xsection GCD property **Curve Length Extended Aligned** is less than the machine property **Max Jaw Distance**.
- **Required jaw width:** transverse Xsection GCD property **Curve Length Extended Orthogonal** is less than the machine property **Jaw Length**.

A machine has longitudinal pull capability if the machine property **Longitudinal Pull Capability** is **true**. Such a machine is feasible if it can accommodate the dimensions of the blank, provide the required pull force, and accommodate the curvature of the part; that is, a longitudinal machine is feasible if all the following hold:

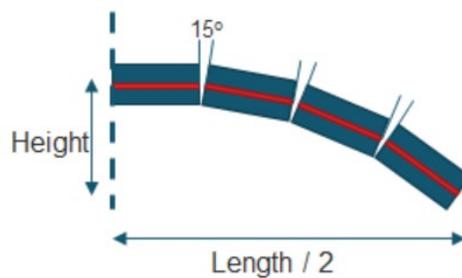
- **Required pull force:** the pull force required for the part does not exceed the machine's pull force capability (specified by the machine property **Press Force**). The required pull force, for a part and a given material, is proportional to the area of the Xsection orthogonal to the pull direction. See [Required Pull Force for Stretch Forming](#) for more information.
- **Required length:** longitudinal Xsection GCD property **Curve Length Extended Aligned** is less than the machine property **Max Jaw Distance**.
- **Required jaw width:** longitudinal Xsection GCD property **Curve Length Extended Orthogonal** is less than the machine property **Jaw Length**.
- **Required curvature:** part length-to-height aspect ratio in the transverse direction must not be less than the machine's minimum achievable length-to-height aspect ratio for a jaw set (the set of jaws gripping along one side of the blank).

The part aspect ratio in the transverse direction is the length of the transverse Xsection divided by its height:

- The length is the difference between the y components of the Xsection properties **Rectangle Lower Left** and **Rectangle Upper Right**.
- The height is determined as described in [Xsection Curve Height for Stretch Forming](#).

The minimum jaw set aspect ratio depends on the following:

- Individual gripper length (specified by the cost model variable **gripperIndividualLength**--304.8mm in starting point VPEs)
- Maximum angle by which a gripper's orientation can differ from an adjacent gripper's orientation (specified by the cost model variable **gripperMaxRotationAngle**--15 degrees in starting point VPEs)



- Maximum jaw set length, specified by the machine property **Jaw Length**. (The number of grippers is estimated as this value divided by individual gripper length.)

Required Pull Force for Stretch Forming

The pull force required for stretching is given by the following formulas:

Required Transverse Pull Force = Flow Stress * Longitudinal Cross Sectional Area

Required pull force for transverse stretching is the product of the following:

- Flow stress (see formula)
- Longitudinal cross-sectional area: this is the area of the longitudinal Xsection (see formula)

Required Longitudinal Pull Force = Flow Stress * Transverse Cross Sectional Area

Required pull force is the product of the following:

- Flow stress (see formula)
- Transverse cross-sectional area: this is the area of the transverse Xsection (see formula)

Flow Stress = (Solution Treated Tensile Yield Strength + Solution Treated Ultimate Tensile Strength) / 2

Flow stress depends on the following material properties:

- Solution treated tensile yield strength: specified by the material property **Annealed Tensile Yield Strength**.
- Solution treated ultimate tensile strength: specified by the material property **Annealed Ultimate Tensile Strength**.

Longitudinal Cross Sectional Area = Longitudinal Length * Stock Thickness

This is the area of the longitudinal Xsection. Longitudinal cross-sectional area is the product of the following:

- Longitudinal length: specified by the **Curve Length Extended Aligned** property of the longitudinal Xsection.
- Stock thickness (thickness of the selected stock--see [Material Stock Selection for Stretch Forming](#))

Transverse Cross Sectional Area = Transverse Length * Stock Thickness

This is the area of the transverse Xsection. Transverse cross-sectional area is the product of the following:

- Transverse length: specified by the **Curve Length Extended Aligned** property of the transverse Xsection.
- Stock thickness (thickness of the selected stock--see [Material Stock Selection for Stretch Forming](#))

Bench Operation Machine Selection

For the Bench Operation process, the cost model selects the feasible machine with the smallest length (specified by the machine property **Usable Length**).

A machine is considered feasible if it can accommodate the dimensions of the selected stock (with the stock oriented so that its width dimension is perpendicular to the ceiling). In particular, the machine is feasible if both the following hold:

- Machine property **Usable Height** is greater than or equal to the stock width.
- Machine property **Usable Length** is greater than or equal to the stock length.

See [Material Stock Selection for Stretch Forming](#) for information about stock length and width.

Note that aPriori selects only from preferred machines, if there is a feasible preferred machine and the cost model variable **usePreferredMachines** is set to **true** (the default in starting point VPEs). If there is no feasible preferred machine, or if the cost model variable **usePreferredMachines** is set to **false**, aPriori selects from all machines. A machine is preferred if the machine property **isPreferred** (typically displayed as **Is Preferred**) is **true**.

Router Machine Selection

Starting point VPEs assume a single machine that represents a hand router. If a VPE administrator adds machines, aPriori selects only from preferred machines, if there is a preferred machine and the cost model variable **usePreferredMachines** is set to **true** (the default in starting point VPEs). If there is no preferred machine, or if the cost model

variable `usePreferredMachines` is set to `false`, aPiori selects from all machines. A machine is preferred if the machine property `isPreferred` (typically displayed as `Is Preferred`) is `true`.

Material Stock Selection for Stretch Forming

The Stretch Forming cost model selects stock for a part based on the following:

- Blank thickness
- Length and width of the stretch-direction-aligned bounding rectangle of the flattened part (that is, length and width of the smallest rectangle with one side aligned with the stretch direction and an interior that contains the entire outline of the flattened part)
- Length and width addendum values (providing additional material for the machine jaws to grip), specified by cost model variables

The cost model finds the actual stock with both the following:

- Thickness that is within 0.5mm of the blank thickness
- One of the following:
 - Smallest length greater than or equal to the part's *minimum required stock length*, and smallest width greater than or equal to the part's *minimum required stock width*
 - Smallest length greater than or equal to the part's *minimum required stock width*, and smallest width greater than or equal to the part's *minimum required stock length*

The part's minimum required stock length is the given by the following:

$$\text{Minimum Required Stock Length} = \text{Xsection-aligned SER Length} + (\text{Length Addendum} * 2)$$

where

- Xsection-aligned SER length is the value of the property **Curve Length Extended Aligned** for the Xsection aligned with the stretching direction (that is, for the transverse Xsection if the current routing includes Stretch Form—Transverse, and for the longitudinal Xsection if the current routing includes Stretch Form—Longitudinal—see [Stretch Form Process Feasibility](#)).
- Length addendum is the value of the cost model variable `stretchFormAlignedMaterialAddendum` (500mm in starting point VPEs).

The part's minimum required stock width is the given by the following:

$$\text{Minimum Required Stock Width} = \text{Xsection-aligned SER Width} + (\text{Width Addendum} * 2)$$

where

- Xsection-aligned SER width is the value of the property **Curve Length Extended Orthogonal** for the Xsection aligned with the stretching direction (that is, for the transverse Xsection if the current routing includes Stretch Form—Transverse,

and for the longitudinal Xsection if the current routing includes Stretch Form—Longitudinal--see [Stretch Form Process Feasibility](#)).

- Addendum is the value of the cost model variable **stretchFormOrthogonalMaterialAddendum** (50mm in starting point VPEs).

If no suitable actual stock is found, aPriori selects virtual stock with the required dimensions.

The cost model currently assumes only one part is made per stock unit.

Formulas for Stretch Forming

This section covers the following topics:

- Yields for Stretch Forming
- Material Cost and Utilization for Stretch Forming
- Labor and Setup Costs for Stretch Forming
- Cycle Time for the Stretch Form Process
- Expendable Tooling Cost for the Stretch Form Process
- Formulas for the Bench Operation Process
- Formulas for the Cold Storage Process
- Formulas for the Router Process

See also [Stretch Forming Tooling](#) and the chapter [Direct and Indirect Overhead](#).

Yields for Stretch Forming

Stretch Forming processes use the following formulas:

Final Yield = Final Output Volume / Local Input Volume

Final yield affects material, labor, and overhead costs per part. It is the fraction of parts created by this process in the current production scenario that will survive as good parts once any secondary processes are completed. That is, final yield is the fraction of parts created by this process that are *not* discarded as scrap parts, either by this process or by a downstream process. Final yield depends on the following:

- Final output volume is the number of parts created by this process that are *not* discarded as scrap parts, either by this process or by a downstream process. It is the product of the annual volume and number of production years, specified in the Production Scenario screen of the Cost Guide.
- Local Input volume (see the formula below). This is the total number of parts produced by this process, including all parts discarded as scrap from this process or downstream processes.

Local Input Volume = Local Output Volume + Number of Scrap Parts for This Process

Local input volume is the total number of parts produced by this process in the current scenario, including all parts discarded as scrap from this process or downstream processes. It is the sum of the following:

- Local output volume (see the formula below). This is the number of parts produced by this process, excluding parts discarded as scrap by this process, but including parts that are discarded as scrap by downstream processes.
- Number of scrap parts for this process (see the formula below)

Local Output Volume = Final Output Volume + Number of Scrap Parts Downstream

Local output volume is the number of parts produced by this process in the current scenario, excluding parts discarded as scrap by this process, but including parts that are discarded as scrap by downstream processes. It is the sum of the following:

- Final output volume is the number of parts created by this process that are *not* discarded as scrap parts, either by this process or by a downstream process. It is the product of the annual volume and number of production years, specified in the Production Scenario screen of the Cost Guide
- Number of Scrap Parts Downstream. This the number of parts discarded as scrap by downstream processes.

Number of Scrap Parts for This Process = (Local Output Volume / Local Good Part Yield) – Local Output Volume

Number of scrap parts for this process is the number of parts produced by this process in the current scenario that are discarded as scrap by this process, before any downstream process is performed on them. It is a function of the following:

- Local output volume (see the formula above). This is the number of parts produced by this process, excluding parts discarded as scrap by this process, but including parts that are discarded as scrap by downstream processes.
- Local good part yield (specified by the machine property **Good Part Yield**). This is the fraction of parts produced by this process that are not discarded as scrap by this process but may be discarded as scrap by downstream processes.

Material Cost and Utilization for Stretch Forming

Material Cost = Raw Material Cost – Scrap Material Credit – Scrap Part Credit

Material Cost depends on the following:

- Raw material cost: see formula
- Scrap material credit: this is 0 if the setup option [Enable Scrap Material Credit](#) is un-checked (the default in starting point VPEs). Otherwise, it is specified by the formula below.
- Scrap part credit: this is 0 if the setup option [Enable Scrap Part Credit](#) is un-checked (the default in starting point VPEs). Otherwise, it is specified by the formula below.

Raw Material Cost = (Material Cost Per Mass * Rough Mass) / Final Yield

Raw material cost is the cost of material for one part, including the cost of scrap produced during manufacture of the part, as well as the amortized cost of scrapped parts. It depends on the following:

- Material cost per mass: specified by the material property **Cost per KG**.
- Rough mass: see formula.
- Final yield: see [Yields for Stretch Forming](#).

Rough Mass = Finish Mass / Utilization

Rough mass depends on the following:

- Finish mass: product of part **Volume** and material **Density**.
- Utilization: calculated by the cost engine. This is part mass divided by stock mass. See [Material Stock Selection for Stretch Forming](#).

Scrap Material Credit = Material Cost Per Mass * Scrap Cost Percent * Scrap Mass

Scrap material credit is the product of the following:

- Material cost per mass: specified by the material property **Cost per KG**.
- Scrap cost percent: this is 0 if the setup option [Enable Scrap Material Credit](#) is un-checked (the default in starting point VPEs). Otherwise, it is specified as a percentage by the material property **Scrap Cost Percent**.
- Scrap mass: see formula.

Scrap Mass = Rough Mass – Finish Mass

Scrap mass depends on the following:

- Rough mass: see formula.
- Finish mass: product of part **Volume** and material **Density**.

**Scrap Part Credit =
(Material Cost per Kg * Scrap Cost Fraction) *
((Number of Scrap Parts + Number of Scrap Parts Down Stream) *
Rough Mass) /
Total Production Volume**

Scrap part credit is 0 if the setup option [Enable Scrap Part Credit](#) is set to **false**.

Otherwise, it is the product of the following:

- Material cost per mass: specified by the material property **Cost per KG**.
- Scrap cost fraction: this is 0 if the setup option [Enable Scrap Part Credit](#) is un-checked (the default in starting point VPEs). Otherwise, it is specified as a percentage by the material property **Scrap Cost Percent**.
- Number of scrap parts: number of parts discarded as scrap by this process. See [Yields for Stretch Forming](#).
- Number of scrap parts down stream: number of parts discarded as scrap by downstream processes. See [Yields for Stretch Forming](#).
- Rough mass: see formula.

- Total production volume: specified in the Production Scenario tab of the Cost Guide.

Labor and Setup Costs for Stretch Forming

The processes Bench Operation, Stretch Form, Cold Storage and Router use the formulas in this section (but note that in the absence of manual forming, setup cost is 0 for Bench Operation):

Labor Cost = Labor Time * Labor Rate / Final Yield

Labor cost depends on the following:

- Labor time (see formula below)
- Labor rate (specified as a machine property)
- Final yield (see [Yields for Stretch Forming](#))

Labor Time = Cycle Time * Number of Operators * Labor Time Standard

Labor time (except for the Cold Storage process) is the product of the following:

- Cycle time (see process-specific Cycle Time formulas)
- Number of operators (specified as a machine property)
- Labor time standard: specified as the machine property **Labor Time Standard**. This multiplier is used to account for otherwise unaccounted for factors that affect labor time, such as operator fatigue or time spent by the operator for cleaning or maintenance.

See also [Formulas for the Cold Storage Process](#).

Amortized Batch Setup = (Setup Time * (Labor Rate + Direct Overhead Rate)) / Batch Size

Batch setup cost per part depends on the following:

- Setup time (specified as the machine property **Setup Time**)
- Labor rate (specified by the machine property **Labor Rate**)
- Direct overhead rate (see [Direct and Indirect Overhead](#))
- Batch size (specified in the **Production Scenario** screen of the Cost Guide)

In the absence of manual forming, setup cost is 0 for Bench Operation.

Cycle Time for the Stretch Form Process

Cycle Time = Process Time * Cycle Time Adjustment Factor

Cycle time is the product of the following:

- Process time: unadjusted cycle time for the current process. See the formula below.
- Cycle Time Adjustment Factor: value of the cost model variable **cycleTimeAdjustmentFactor**. This is set to 1 in aPriori starting point VPEs. VPE administrators can change the cost model variable to globally adjust cycle times.

Process Time = Identing Time + Locating Hole Drilling Time + Child Operation Time

Process time is the sum of the following:

- Identing time: this is the time required to vibro-etch onto the part a unique identifier (to enable traceability of the part). The total identifying time is specified by the cost model variable **defaultIdentingTime** (45 seconds in starting point VPEs). If the current routing includes multiple stretches (see [Number of Stretch Form Cycles](#)), this time is amortized over the stretches (that is, the identifying time attributed to one process instance is **defaultIdentingTime** divided by the number of stretches).
- Locating-hole drilling time: this is the time required to drill the locating hole. The total locating-hole drilling time is specified by the cost model variable **defaultLocatingHoleDrillingTime** (4 minutes in starting point VPEs). If the current routing includes multiple stretches (see [Number of Stretch Form Cycles](#)), this time is amortized over the stretches (that is, the locating-hole drilling time attributed to one process instance is **defaultLocatingHoleDrillingTime** divided by the number of stretches).
- Child operation time is the sum of the following:
 - Inspecting: inspection time required between stretches. By default this is specified by the cost model variable **defaultInterStretchInspectionTime** (30 seconds in starting point VPEs). Users can override the default on a part-by-part basis with the setup option [Inter Stretch Inspection Time](#).
 - Loading: time required to load the part onto the machine. This is looked up by stock mass in the lookup table **tblMaterialHandling**.
 - Pre-Stretching: time required for pre-stretching on tangential machines is specified by the machine property **Pre Stretch Cycle Time**. Pre-stretching time is 0 for simple (non-tangential) machines.
 - Stretch Forming: this is the time required for the stretching operation. The total stretching time is the ram stroke distance (the part height) divided by the machine's ram stroke speed (specified by the machine property **Ram Stroke Speed**). If the current routing includes multiple stretches (see [Number of Stretch Form Cycles](#)), the stroke distance is amortized over the stretches (that is, the stroke distance attributed to one operation instance is the part height divided by the number of stretches).
 - Tool cleaning: this is the time required to clean the tool between stretches. It is looked up by form area in the lookup table **tblStretchForm**, and bounded below by the cost model variable **minimmToolCleanTime** (5 seconds in starting point VPEs). The form area is the sum of the areas of all forms of type EMBOSS.
 - Tool Lubricating: this is the time required to lubricate the tool between stretches. It includes time to apply the lubricant as well as time to wipe away the excess. The default time to apply the lubricant is specified by the cost model variable **defaultApplyLubricantTime** (30 seconds in starting point VPEs). Users can override the default with the setup option [Lubricant Application Time](#). Time to wipe away the excess is looked up by form area in the lookup table **tblStretchForm**. The form area is the sum of the areas of all forms of type EMBOSS.

- Unloading: time required to unload the part from the machine. This is looked up by stock mass in the lookup table **tblMaterialHandling**.

Expendable Tooling Cost for the Stretch Form Process

This is the sum of the operation-level expendable tooling costs:

- Tool Cleaning expendable tooling cost: the cost for wet wipes used to clean the tool between stretches. The cost model assumes the use of one wet wipe for every 4 meters of form area. The form area is the sum of the areas of all forms of type EMBOSS. The model assumes that at least one wet wipe is used, and that a whole number of wet wipes is used. The cost per wet wipe is specified by the tool shop variable **consumableMaterial_CleaningWipes**.
- Tool Lubricating expendable tooling cost: the cost for lubricant and wet wipes (used to remove excess lubricant). Wet wipes cost is calculated as for Tool Cleaning (see above). The cost model assumes the use of 0.2 liters of lubricant per square meter of form area. The form area is the sum of the areas of all forms of type EMBOSS. The cost per liter is specified by the tool shop variable **consumableMaterial_LubricatingSolution**.

Formulas for the Bench Operation Process

See also [Stretch Forming Tooling](#).

Cycle Time = Process Time * Cycle Time Adjustment Factor

Cycle time is the product of the following:

- Process time: unadjusted cycle time for the current process. See the formula below.
- Cycle Time Adjustment Factor: value of the cost model variable **cycleTimeAdjustmentFactor**. This is set to 1 in aPiori starting point VPEs. VPE administrators can change the cost model variable to globally adjust cycle times.

Process Time = Handling Time + Manual Clean Time + Inspecting Time + Manual Forming Time

Process time is the sum of the following:

- Handling time: this includes loading and unloading time. Both are looked up by stock mass in the lookup table **tblMaterialHandling**.
- Manual clean time: this is the time required to clean the formed part. It is looked up by blank area in the lookup table **tblStretchForm**, and bounded below by the cost model variable **minimmManualCleanTime** (10 seconds in starting point VPEs). Blank area includes the surface area of both sides of the blank—it is twice the product of the blank's length and width.
- Inspecting time: this is the time to inspect the formed part. By default, it is specified by the cost model variable **defaultFinalInspectionTime** (5 minutes in starting point VPEs). Users can override the default with the setup option **Final Inspection Time**.

- Manual Forming time: this is the sum of the cycle times for the Manual Forming operations. The time for each form on which this operation is performed is the length of the form divided by the value of the cost model variable **defaultManualFormFormingRate** (50mm/minute in starting point VPEs).

Expendable Tooling Cost

This is the cost for wet wipes used to clean the formed part. The cost model assumes the use of one wet wipe for every 4 meters of blank area. Blank area includes the surface area of both sides of the blank—it is twice the product of the blank's length and width. The model assumes that at least one wet wipe is used, and that a whole number of wet wipes is used. The cost per wet wipe is specified by the tool shop variable **consumableMaterial_CleaningWipes**.

Formulas for the Cold Storage Process

Labor Time = Handling Time * Number of Operators * Labor Time Standard

Labor time (except for the Cold Storage process) is the product of the following:

- Handling time: this is load and unload time. Each time is looked up by blank mass in the lookup table **tblMaterialHandling**.
- Number of operators (specified as a machine property)
- Labor time standard: specified as the machine property **Labor Time Standard**. This multiplier is used to account for otherwise unaccounted for factors that affect labor time, such as operator fatigue or time spent by the operator for cleaning or maintenance.

Cycle Time = Handling Time + Storage Time

- Handling time: this is load and unload time. Each time is looked up by blank mass in the lookup table **tblMaterialHandling**.
- Storage time: by default this is specified by the cost model variable **defaultColdStorageTime** (24 hours in starting point VPEs). Users can override the default with the setup option **Cold Storage Time**.

Formulas for the Router Process

Cycle Time = Handling Time + Cutting Time

- Handling time: this is load and unload time. Each time is looked up by blank mass in the lookup table **tblMaterialHandling**.
- Cutting time (see formula)

Cutting Time = Tool Engaged Time + (2 * Rapid Traverse Time)

Cutting time depends on the following:

- Tool engaged time (see formula)
- Rapid traverse time (see formula)

Tool Engaged Time = (Profile Perimeter / Machine Feed Rate)

Tool engaged time depends on the following:

- Profile perimeter: this is the sum of the lengths of the blank edges.
- Machine feed rate (specified by the machine property **Feed Rate**)

Rapid Traverse Time = ((Part Length / 2) / Machine Rapid Traverse Rate)

Rapid traverse time depends on the following:

- Part length
- Machine rapid traverse rate (specified by the machine property **Rapid Traverse Rate**)

See also [Stretch Forming Tooling](#).

User Inputs for Stretch Forming

Setup options are covered in the following sections:

- [Setup Options for Stretch Forming Cycles](#)
- [Setup Option for Cold Storage](#)
- [Setup Options for Bench Operation](#)
- [Setup Options for Router](#)

Setup Options for Sheet Metal – Stretch Forming

The routing node Sheet Metal – Stretch Forming provides the following options:

- [Enable Scrap Material Credit](#)
- [Enable Scrap Part Credit](#)

Enable Scrap Material Credit

By default in starting point VPEs, the cost model assumes that material scrap (such as trim scrap) is *not* sold for credit. Administrators can customize the default with the cost model variable **enableScrapMaterialCredit** (**false** in starting point VPEs). With this setup option, users can override the default on a per-part basis.

Enabling scrap material credit increases material utilization and decreases material cost. The credit rate is specified as a percentage of the material rate by the material property **Scrap Cost Percent**. See [Material Cost and Utilization for Stretch Forming](#).

Enable Scrap Part Credit

By default in starting point VPEs, the cost model assumes that the material from scrapped parts is *not* sold for credit. Administrators can customize the default with the cost model variable **enableScrapPartCredit** (**false** in starting point VPEs). With this setup option, users can override the default on a per-part basis.

Enabling scrap part credit increases material utilization and decreases material cost. This includes credit for parts scrapped by this process as well as by downstream processes. The credit rate is specified as a percentage of the material rate by the material property **Scrap Cost Percent**. See [Material Cost and Utilization for Stretch Forming](#).

Setup Options for Stretch Forming Cycles

The routing node Stretch Forming Cycles provides the following options:

- Number of Stretch Form Cycles
- Inter Stretch Inspection Time
- Lubricant Application Time
- Tooling Cost
- Number of Forming Block Tools Required
- Counter Form Tooling Cost
- Number of Counter Form Tools

Number of Stretch Form Cycles

By default in starting point VPEs, the number of Stretch Form cycles is specified by the cost model variable **defaultNumStretches** (1 in starting point VPEs). See [Routing for Stretch Forming](#). You can override the default with this setup option.

Inter Stretch Inspection Time

By default in starting point VPEs, the time required for inspection between stretches is specified by the cost model variable **defaultInterStretchInspectionTime** (30 seconds in starting point VPEs). See [Cycle Time for the Stretch Form Process](#). You can override the default with this setup option.

Lubricant Application Time

By default in starting point VPEs, the time required to lubricate the tool between stretches is specified by the cost model variable **defaultApplyLubricantTime** (30 seconds in starting point VPEs). See [Cycle Time for the Stretch Form Process](#). You can override the default with this setup option.

Tooling Cost

By default, the cost for the stretch forming tool is the product of the cost per unit area, the form area, and a region multiplier. See [Stretch Forming Tooling](#). You can override the default with this setup option.

Number of Forming Block Tools Required

By default in starting point VPEs, tooling cost calculations assume that a single tool lasts long enough to produce the production volume specified in any scenario. VPE administrators can customize the default number of tools assumed for the current production scenario (with the cost model variable **defaultNumFormingBlocksRequired**). Users can override the default on a per-part basis and specify the number of tools with this setup option. The cost model accounts for the specified number of tools in total hard tooling cost.

Counter Form Tooling Cost

You can override the default tooling cost for a counter form with this setup option.

Number of Counter Form Tools

By default in starting point VPEs, tooling cost calculations assume that a single tool lasts long enough to produce the production volume specified in any scenario. VPE administrators can customize the default number of tools assumed for the current production scenario (with the cost model variable **defaultNumCounterFormToolsRequired**). Users can override the default on a per-part basis and specify the number of tools with this setup option. The cost model accounts for the specified number of tools in total hard tooling cost.

Setup Option for Cold Storage

Cold storage provides the option Cold Storage Time.

Cold Storage Time

By default in starting point VPEs, the time spent by the annealed stock in cold storage is specified by the cost model variable **defaultColdStorageTime** (24 hours in starting point VPEs). See [Formulas for the Cold Storage Process](#). You can override the default with this setup option.

Setup Options for Bench Operation

Bench Operation provides the following option:

- Final Inspection Time
- Tooling Cost
- Number of Tools Required

Final Inspection Time

By default in starting point VPEs, the final inspection time is specified by the cost model variable **defaultFinalInspectionTime** (5 minutes in starting point VPEs). See [Formulas for the Bench Operation Process](#) and [Formulas for the Cold Storage Process](#). You can override the default with this setup option.

Tooling Cost

By default, the tool cost for the Manual Forming operation of the Bench Operation process is a fraction of the Stretch Form tooling cost, where the fraction is specified by the cost model variable **defaultManualFormingToolingMultiplier** (0.2 in starting point VPEs). See [Stretch Forming Tooling](#). You can override the default with this setup option.

Number of Tools Required

By default in starting point VPEs, tooling cost calculations assume that a single tool lasts long enough to produce the production volume specified in any scenario. VPE administrators can customize the default number of tools assumed for the current production scenario (with the cost model variable **manualFormingBlockNumberOfPartsLife**). Users can override the default on a per-part basis and specify the number of tools with this setup option. The cost model accounts for the specified number of tools in total hard tooling cost.

Setup Options for Router

The Router process provides the setup options Tooling Cost and Number of Tools Required.

Tooling Cost

By default, the tool cost for the Manual Forming operation of the Bench Operation process is the product of the cost per unit area, the form area, and a region multiplier. See [Stretch Forming Tooling](#). You can override the default with this setup option.

Number of Tools Required

By default in starting point VPEs, tooling cost calculations assume that a single tool lasts long enough to produce the production volume specified in any scenario. VPE administrators can customize the default number of tools assumed for the current production scenario (with the cost model variables `routerJigNumberOfPartsLife`). Users can override the default on a per-part basis and specify the number of tools with this setup option. The cost model accounts for the specified number of tools in total hard tooling cost.

Process Defaults and Thresholds for Stretch Forming

Following are some of the important cost model variables for the Stretch Forming process group:

allowableHullToCurveRatio	See Stretch Form Process Feasibility .
defaultApplyLubricantTime	See Cycle Time for the Stretch Form Process .
defaultColdStorageTime	See Formulas for the Cold Storage Process .
defaultFinalInspectionTime	See Formulas for the Bench Operation Process .
defaultIdentingTime	See Cycle Time for the Stretch Form Process .
defaultInterStretchInspectionTime	See Cycle Time for the Stretch Form Process .
defaultLocatingHoleDrillingTime	See Cycle Time for the Stretch Form Process .
defaultManualFormFormingRate	See Formulas for the Bench Operation Process .
defaultManualFormingToolingMultiplier	See Stretch Forming Tooling .
defaultNumStretches	See Routing for Stretch Forming .
defaultRouterJigToolingCost	See Stretch Forming Tooling .
defaultStretchFormToolingCost	See Stretch Forming Tooling .
enableScrapMaterialCredit	See Enable Scrap Material Credit .
enableScrapPartCredit	See Enable Scrap Part Credit .
regionMultiplier	See Stretch Forming Tooling .
stretchFormAlignedMaterialAddendum	See Material Stock Selection for Stretch Forming .

stretchFormOrthogonalMaterialAddendum	See Material Stock Selection for Stretch Forming .
usePreferredMachines	See Machine Selection for Stretch Forming .

17 Plastic Molding Process Group

This section describes the costing details and inputs that are available for the following three members of the Plastic Molding process group: Injection Molding (IM), Structural Foam Molding (SFM), and Reaction Injection Molding (RIM). For these processes, aPriori estimates manufacturing times and costs for single-shot, molded parts (including cost estimates for manufacturing the required mold). The routing can include secondary surface treatment and packaging processes (if you have licensed these modules). A future release will support secondary *machining* processes on molded parts

This chapter includes the following topics:

- Cost Model Overview
 - Costing Flow
 - Cost Algorithms and Calculations
 - User Inputs for Plastic Molding
 - Process Defaults and Thresholds
 - Design-to-cost Configuration for Plastic Molding
-

Cost Model Overview

In general, plastic molding costs are determined by aggregating material, labor, machine, and tooling costs. This overview section summarizes assumptions and limitations of the following aspects of the model:

- General Process for Plastic Molding
- Part Geometry for Plastic Molding
- Materials for Plastic Molding
- Machines for Plastic Molding
- Tooling for Plastic Molding

General Process for Plastic Molding

aPiori's plastic molding process model assumes all the following:

- Single part (multiple mold cavities are supported, but each cavity must handle the identical part design)
- Single shot
- Single material
- Single color
- Two or three plate mold

IM and SFM support thermoplastic material only. RIM supports thermosetting plastic only.

Subprocesses and Machine Types

The model also does *not* support any of the following subprocesses and machine types:

- In-mold labeling
- In-mold assembled components
- Insert molding
- Co-molding
- Over molding
- Stack molding

Material Utilization

The process model assumes the following regarding material utilization:

- Flash is minimized due to the high clamping capabilities of the machines.
- Some setup time is required to test molding. All parts created during mold testing are scrapped, and costs for this scrap are included in the overall cost of the part. See [Other Direct Costs](#) for Plastic Molding.
- During processing, individual part waste is a function of the required volume of runners and (for IM and SFM) the available regrind amount. (No regrind allowance is made for RIM, since thermosetting polymers cannot be reused.) The percent yield of the process is also a function of the average utilization of the machine, as well as mold efficiency. Typical yields are 95%. See [Operation-level](#)

[Feasibility and Routing and Material Utilization for Plastic Molding](#) for more information.

Additional Limitations

The model

- *Does not* attempt to estimate the required number of hot drops. You must enter this number manually by using **Process Setup Options**.
- *Does not* account for part defects like sink marks, short shots, bubbles, warping, or ejector marks.

Part Geometry for Plastic Molding

Feasible geometries for IM and RIM are limited only by machine capabilities. A part is geometrically feasible for IM and RIM if and only if some machine that is included in the VPE satisfies both the following requirements:

- It is able to accommodate the horizontal and vertical dimensions of the mold base required for the part.
- It is able to provide the clamp force required for the part. (The required clamp force is a function of the part's geometry as well as the material to be used.)

Feasible geometries for SFM must satisfy the requirements just described for IM and RIM, and must also have an average wall thickness not less than a plant-variable-specified minimum. See [Additional SFM Feasibility Checks](#).

See [GCD Extraction for Plastic Molding](#) for more information on part geometry, and [Machine Feasibility and Selection](#) for more information on machine selection.

Materials for Plastic Molding

The IM and SFM cost models only support the molding of thermoplastic materials. The RIM cost model only supports the molding of thermosetting materials. The cost models assume that the material is delivered in pellet form. The model relies on the following properties of the various supported materials:

- `Unit Cost (USD/kg)`: influences total material cost (volumetric).
- `Min Clamping Force` and `Max Clamping Force (MPa)`: determine the required clamping force of the machine.
- `Density (kg/m3)`: influences total material cost (volumetric).
- `Eject Deflection Temp (°C)`: influences part cooling time.
- `Melting Temp (°C)`: influences part cooling time.
- `Mold Temp (°C)`: influences part cooling time.
- `Thermal Conductivity (watt/kg°C)`: influences part cooling time.
- `Density of Melt (kg/m3)`: influences part cooling time.
- `Specific Heat of Melt (joule/g°C)`: influences part cooling time

See [Material Feasibility and Selection](#) for more information.

Machines for Plastic Molding

The plastic molding machines in the aPriori baseline VPE only cover single-shot, single-part, single-material, single-color molding.

Brand names of IM and SFM machines in the baseline VPE include the following:

- Arburg
- Engel
- Kawaguchi
- KraussMaffei
- Milacron
- Netstal
- Toyo

Specialized SFM machines include machines from the Uniloy line. These are capable of both physical gas injection and use of chemical foaming agents. All other plastic molding machines, if used for structural foam molding, are only capable of using chemical foaming agents.

For RIM, the cost model assumes a Gusmer-Decker Reactor IP-40.

The characteristics of these machines fall into the following ranges:

Machine Characteristic	Low End	High End
Overhead Rate	\$23.19 per hour	
Dry Cycle Time	1.1 seconds	
Injection Rate	64,000 mm ³ per second	3,710,000 mm ³ per second
Clamping Force	300 kN	55,000 kN
Max Mold Height	300 millimeters	3,300 millimeters
Min Mold Height	150 millimeters	1,500 millimeters
Tie Bar Distance (Horizontal and Vertical)	221 millimeters	2,500 millimeters

See [Machine Feasibility and Selection](#) for more information.

Tooling for Plastic Molding

The tooling model supports single cavity and multi-cavity molds for single parts.

Molds can be machined out of the following types of material:

- P20 Tool Steel
- H13 Tool Steel
- Stainless Steel
- Carbon Steel
- Aluminum
- Epoxy

Note that Epoxy is not an option for the action and ejector box material.

Both catalog and custom mold bases are supported.

The Injection Molding tooling model aggregates costs in the following categories associated with hard tooling, and presents them as a bill of materials:

- Material costs: raw materials for core and cavity plates, ejector boxes, actions, and EDM carbon
- Standard purchased item costs: items such as ejector guide pins, locating rings, stop pins, sleeve pins, water hoses, etc.
- Labor costs: labor associated with machining, assembly, mold design, finishing/polishing, spotting, tryout, and CMM inspection
- Miscellaneous costs: heat treatment, plating, stress relief, texture, freight, markup/profit

The tooling model estimates the number of parts that can be produced with a given tool before it wears to the point that it needs to be replaced. Based on that estimate, the cost model determines the number of tools required to manufacture the production volume specified in the Production Scenario tab of the Cost Guide, and accounts for that number of tools in total hard tooling cost.

Tool-life estimation is based on part material, tool material, and tool coating type. For a given costing, either the formula Dependencies or Investment tab displays the number of tools assumed by tooling cost calculations.

See [Tooling Cost](#) for more information.

Costing Flow

Before generating a cost taxonomy, aPriori performs tasks related to the following:

- [GCD Extraction for Plastic Molding](#)
- [How aPriori Selects Draw Direction for Plastic Molding](#)
- [How aPriori Assigns Holes and Voids to Slides and Lifters](#)
- [Feasibility and Routing](#)

GCD Extraction for Plastic Molding

When you choose the Plastic Molding process group, aPriori analyzes your part in terms of geometric cost drivers (GCDs) that include **Surfaces**, **Holes**, **Voids**, and **Combo Voids**, as well as the **Parting Line**, **Draw Direction** (see [How aPriori Selects Draw Direction for Plastic Molding](#)), and slide and lifter **Bundles** (see [How aPriori Assigns Holes and Voids to Slides and Lifters](#)). As usual, there is a special GCD, **Component**, that represents the part as a whole.

For plastic molding parts, the part height dimension is always aligned with the draw direction. Part length is the longer of the remaining dimensions, and part width is the shorter. (Note that this applies only to process groups that involve a parting line, draw direction, or build direction; for other primary process groups, part length \geq part width \geq part height.)

Following are some of the important properties of each of these GCD types:

- **Component:**
 - Volume (mm³)
 - Surface Area (mm²)

- Length, Width, and Height (millimeters)
- Number of Surfaces
- Min Thickness, Max Thickness, and Avg Thickness (millimeters)
- Length Direction, Width Direction, and Height Direction: each of these is a unit vector, two of whose components are 0 (the other component is 1 or -1). These vectors can be compared with the Direction vector of another GCD (such as a Setup Axis) in order to determine whether the GCD's direction is aligned with the part's length, width, or height.
- **Parting Line:**
 - Draw Direction
 - Height (millimeters)
 - Parting Type
 - Projected Area (mm²)
- **Surfaces (Curved Surface, Curved Wall, and Planar Face):**
 - Finished Area (mm²)
 - Bend Diameter (millimeters)
 - Perimeter (millimeters)
 - SER Length and SER Width (smallest enclosing rectangle dimensions in millimeters)
 - Corner Diameter (millimeters)
 - Inside Diameter (millimeters)
 - Number of Surfaces
 - Fillet Min Angle and Fillet Max Angle (degrees)
 - Round Radius (millimeters)
 - Round Length (millimeters)
- **Holes (Simple Hole, Multistep Hole):**
 - Diameter (millimeters),
 - Length and Depth (millimeters)
 - Volume (mm³)
 - Surface Area (mm²)
 - Maximum diameter and Minimum diameter (millimeters—for multistep holes)
 - Step count (for multistep holes)
 - Hole type (THROUGH or BLIND)
 - Blind, Sleeve Pin, Threaded, Countersunk, and Flanged (TRUE or FALSE)
 - Accessibility (THROUGH, OBSCURED, SIDE_A, SIDE_B, or UNDERCUT-- determines operation sequence and tooling requirements.)
- **Volumes (Void, Combo Void):**
 - Box Length, Box Width, Box Height (millimeters)
 - Excluded from Bundling (boolean)
 - Exposed Area (mm²)
 - Number of Surfaces
 - Number of Openings

- Perimeter (mm)
- Surface Area (mm²)
- Tool Reach (millimeters)
- Volume (mm³)
- Maximum Tool Diameter (millimeters)
- Parting Line Draw Distance (millimeters)
- Accessibility (THROUGH, OBSCURED, SIDE_A, SIDE_B, or UNDERCUT-- determines operation sequence and tooling requirements.)

How aPriori Selects Draw Direction for Plastic Molding

aPriori selects a draw direction by (1) identifying a set of candidate directions, (2) assigning a rating to each candidate, and (3) selecting the candidate with the highest rating.

aPriori relies on the values of several site variables in order to perform these steps. Site variable names in this section are followed by their default value in parentheses, as in **siteVarName(default value)**. VPE administrators can adjust these values with the Process Group Site Variables tool in the VPE toolset.

Identifying Candidates

Draw direction candidates are generated from the part features. The candidates include the following:

- Three cardinal directions of the part coordinate system
- Normals to the part's planar faces
- Directions parallel to the axes of symmetry of the part's holes
- For each face that is a portion of a cone or cylinder, directions parallel to the axis of symmetry of the cone or cylinder of which it is a portion
- For each curved wall, directions parallel to that curved wall
- Directions that maximize accessible area of any sheet-like features
- Directions parallel to rib intersections (if **drawDirAnalyzeRibs** is true—the default in starting point VPEs)

Up to **drawDirMaxRayDirs(20)** directions are considered.

Rating Candidates

Each candidate's rating is the sum of its ratings on the following criteria:

- Undercut volume
- Undercut alignment
- Parting line flatness
- Mold box height
- Axis share (hole alignment)
- Accessible sheet area

- Number of pin holes
- Grill alignment
- Rib alignment

For each candidate direction:

Total weight =
Undercut Weight (+ estimated undercut error) +
Undercut Alignment Weight +
Parting Line Flatness Weight +
Mold Box Height Weight +
Axis Share Weight +
Accessible Sheet Area Weight +
Pin Hole Weight +
Grill Weight +
Rib Weight

Input variables to the weight formulas are computed by shooting **drawDirMaxRays(90000)** rays in each of the candidate directions. That is, for each candidate direction, aPriori considers a sampling of rays that run in that direction. It computes the input values by examining the geometric characteristics of the intersections of the rays and the part. The number of rays in each sample is **drawDirMaxRays(90000)**.

Undercut Weight

If the undercut volume for the candidate direction is non-negligible, the undercut rating is based on undercut volume in relation to total part volume:

**If (undercut volume < exactPartVolume *
drawDirMaxNegligibleUndercutToPartVolumeRatio(0.000001))**

Then

undercut weight = drawDirNoUndercutWeight(1)

Else

**undercut weight = drawDirUndercutPresenceFactor(0.5) *
(1 – undercut volume/ (undercut volume + part volume)).**

If **ignoreSimilarVoidVolume(true)** is set to **true**, when draw directions within 10 degrees of each other are compared, aPriori computes the expected change in the undercut volume that assumes voids are similar between draw directions, and only change shape. If the undercut volume difference is within the expected range, undercut volume contribution is not used in the draw direction comparison.

Undercut Alignment Weight

This rating is based on the number of misaligned undercuts:

Undercut alignment weight = drawDirVoidAlignmentFactor(0.5) * Alignment Quality.

Alignment Quality = 1 – number of misaligned undercuts/total number of undercuts.

An undercut is considered misaligned if it is one of the following:

- Hole (simple or complex)

- Shadow which creates an undercut outside its own volume
- Thin undercut internal to an almost vertical wall, where the top part of the wall throws a shadow on the bottom part of the wall, and the wall is within 5 degrees of the draw direction

Parting Line Flatness Weight

If (parting line height < part height in the evaluated direction * drawDirMaxFlatPartingLineToBoxHeightRatio(0.2))

Then

Parting Line Flatness Weight = DrawDirFlatPartingLineWeight(0.2)

Else

Parting Line Flatness Weight =
DrawDirPartingLineFlatnessFactor(0.1) * Flatness

Flatness = Projected Length/Sqrt(Projected Length ^2+ 4 * Parting Line Height ^2).

Parting Line Height = Difference between minimum upper bound and maximum lower bound of the ray intervals that lie on the parting line boundary of the part.

Projected Length = Length of the parting line projected on the plane orthogonal to the candidate direction.

Mold Box Weight

Mold Box Height Weight = drawDirBoxHeightFactor(0.1) *
 minimum part height along any direction / Part height along evaluated direction.

Axis Share Weight

Axis Share Weight = drawAxisShareFactor(0.2) *
 number of holes aligned with draw direction / total number of holes.

Accessible Sheet Area Weight

Accessible Sheet Area Weight = drawAccessibleSheetFactor(0.2) *
 maximum of top /bottom sheet areas accessible from draw direction/ total sheet area.

Pin Hole Weight

Pin Hole Weight = 0 if there is 0 or 1 pin holes, **drawDirPinHoleFactor(1) * 0.5**,
 if there are two; **drawDirPinHoleFactor(1)** if there are three or more pin holes.

Grill Weight

Grill Weight = drawDirPinHoleFactor(1) *
 Number of honeycomb cells of the grills aligned with the evaluated direction /
 Total Number of honeycomb cells in all grills detected on the part.

Rib Weight

Rib Weight = drawDirRibFactor(0.0) * area of ribs parallel to this direction /
 area of all found ribs, if **drawDirAnalyzeRibs(true)** is true; **0.0** otherwise.

Breaking Ties

Candidate directions are pre-sorted by putting the three cardinal directions first, and then sorted by total weighted area of the surfaces associated with a direction.

If several candidates have the same weight within their estimated errors, the candidate that appears earlier in the above pre-sort order is selected. Estimated error is based on comparing the known exact part volume with the undercut volume measured using rays.

Logging

aPriori provides a log of direction selection, which includes the following information:

- Weight calculations for each analyzed direction (shown in green in the example below)
- Current values of the relevant site variables (shown in red)
- Results of part measurements (shown in blue)

Following is an example of log information for one candidate direction:

```
2013-09-04 09:30:30,398 INFO DrawDirectionExtractor - Computing draw
direction weights
2013-09-04 09:30:35,946 INFO DrawDirectionExtractor -
-rejected-
dir = (1.0, 0.0, 0.0), index = 0, total weight = 0.14943 +/- 0.0042
```

```

undercut weight = 0.08687 = 0.5 * 0.17374
parting line flatness weight = 0.04391 = 0.1 * 0.43915
draw distance (box height) weight = 0.01864 = 0.1 * 0.1864
feature weight = 0
_rawBoxHeight=366.63583365360864,
_rawUndercutVolume=434354.65222118184,
_rawTracedPartVolume=92546.0109951705,
_rawPartingLineHeight=362.56069342639995,
_rawPartingLineProjectionLength=354.441334665515
2013-09-04 09:30:35,947 INFO DrawDirectionExtractor -
<++SELECTED++>
dir = (0.0, 1.0, 0.0), index = 1, total weight = 1.53852 +/- 0.00474
undercut weight = 0.37623 = 0.5 * 0.75245
parting line flatness weight = 0.09858 = 0.1 * 0.98579
draw distance (box height) weight = 0.06371 = 0.1 * 0.6371
feature weight = 1 (pin holes = 1.0 * 1)
_rawBoxHeight=107.26950372967542,
_rawUndercutVolume=30048.010636088467,
_rawTracedPartVolume=91796.80456208688,
_rawPartingLineHeight=73.7332503333868,
_rawPartingLineProjectionLength=865.3046818585522

```

How aPriori Assigns Holes and Voids to Slides and Lifters

aPriori analyzes a part's unthreaded holes and voids in order to determine which, if any, must be handled by a slide or lifter. For those GCDs that do require a slide or lifter, aPriori determines which can be grouped together onto a common action. In this way, aPriori can determine the number and size of the slides and lifters required for the part's mold.

Each resulting slide or lifter is represented by a GCD with a name such as **SlideBundle:1** or **SlideBundle:2**, and so forth. These GCDs appear in the Geometric Cost Drivers pane under the **Slide Bundles** or **Lifter Bundles**, which appear under the **Volume** node.

By default, an unthreaded hole or void is assumed to require a slide or lifter if and only if it is obscured, that is, if and only if it is *not* accessible from the draw direction. For SimpleHoles, MultiStepHoles, Voids, and ComboVoids, you can override this default, and specify that an obscured feature does not require a slide or lifter (for example, because it is shallow and has a smooth opening, and so can be safely pulled).

Follow these steps to specify that a feature does not require a slide or lifter:

- 1 Click the GCD either in the Component Viewer or the Geometric Cost Drivers pane.
- 2 Double click the Property Result field for the property **Excluded From Bundling**, and select **true**.

Geometric Cost Drivers			
Show ▾			
Status	Name	O... Name	Property Result
●	⊕ Component	Name	Void:1
●	⊖ Volume	Excluded From Bundling	false
●	⊖ Slide Bundles [2]	Accessibility	true
●	⊖ SlideBundle:1	Void Direction Accessible	false
●	⊖ Void:1	Void Dir Obstruction Distan...	-
	⊕ GCD Relations	Box Height (mm)	0.12
●	⊖ SlideBundle:2	Box Length (mm)	30.46
●	⊖ Lifter Bundles [2]	Box Width (mm)	0.63
●	⊕ Holes	Centroid	(112.09, -2.00, -16.99)
●	⊕ Surfaces	Draw Height (mm)	0.12
●	⊕ Other	Draw Length (mm)	30.46

3 Re-cost the scenario.

This section contains the following subsections:

- Slide Bundling Criteria
- Lifter Bundling Criteria
- Further Bundling Criteria—Breaking Ties
- Determining Action Size

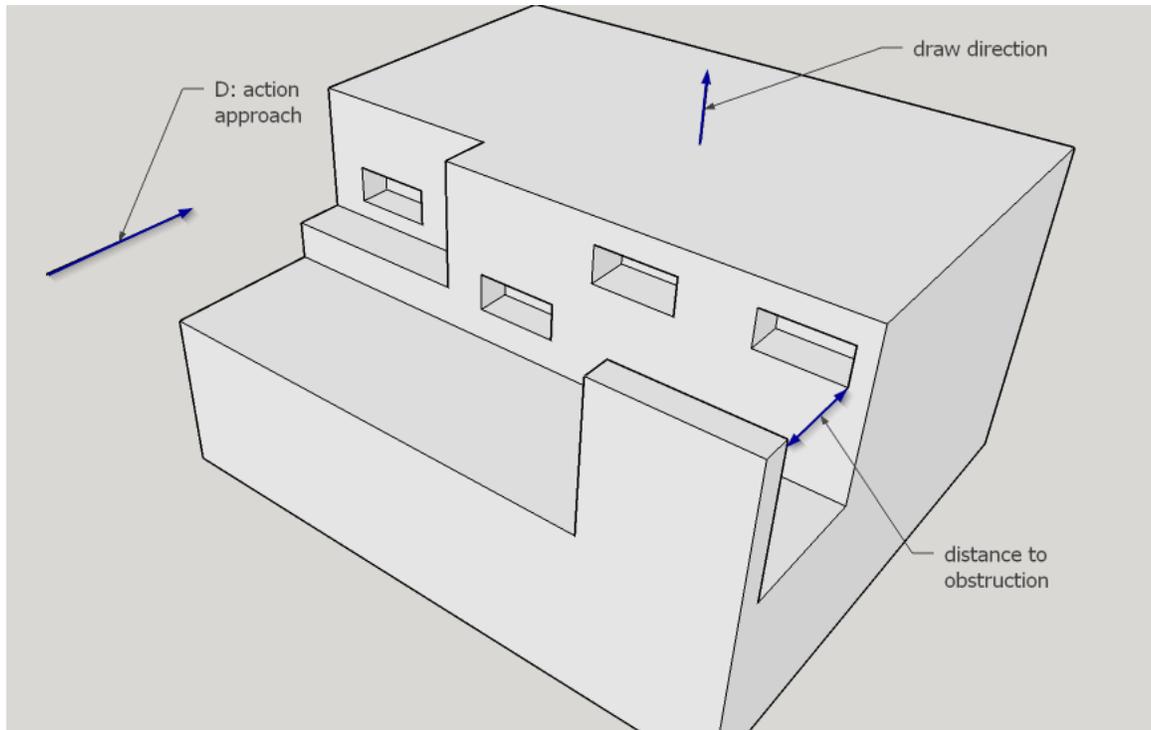
Slide Bundling Criteria

A group of GCDs can form a bundle and be handled by a single slide only if there is a direction, D, (represented by a SetupAxis) such that all the following hold:

- All the GCDs are accessible from D.
- D is sufficiently close to orthogonal to the draw direction.

The cost model variable **drawDirectionOrthogonalEpsilonForSlides** specifies the threshold for being sufficiently close; this value is 30 degrees in aPiori starting point VPEs.

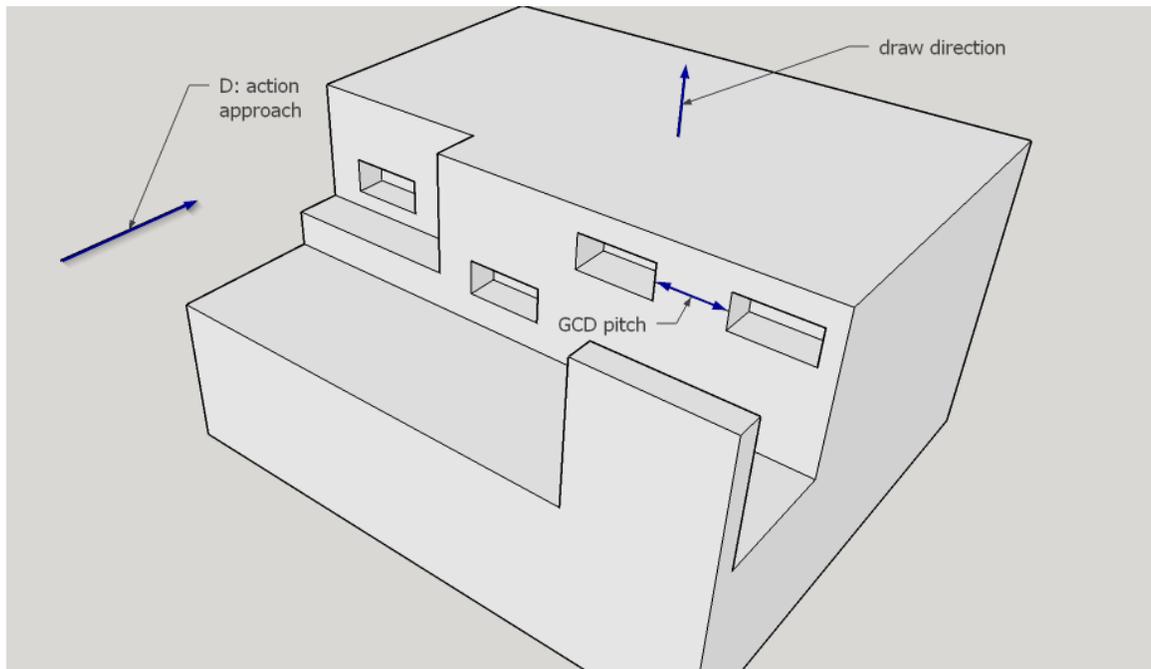
- For each GCD, if access to the GCD from D is obstructed, the obstruction is sufficiently far from the GCD.



The cost model variable **minimumSlideClearance** specifies the threshold for being sufficiently far; this value is 196.75mm in aPriori starting point VPEs.

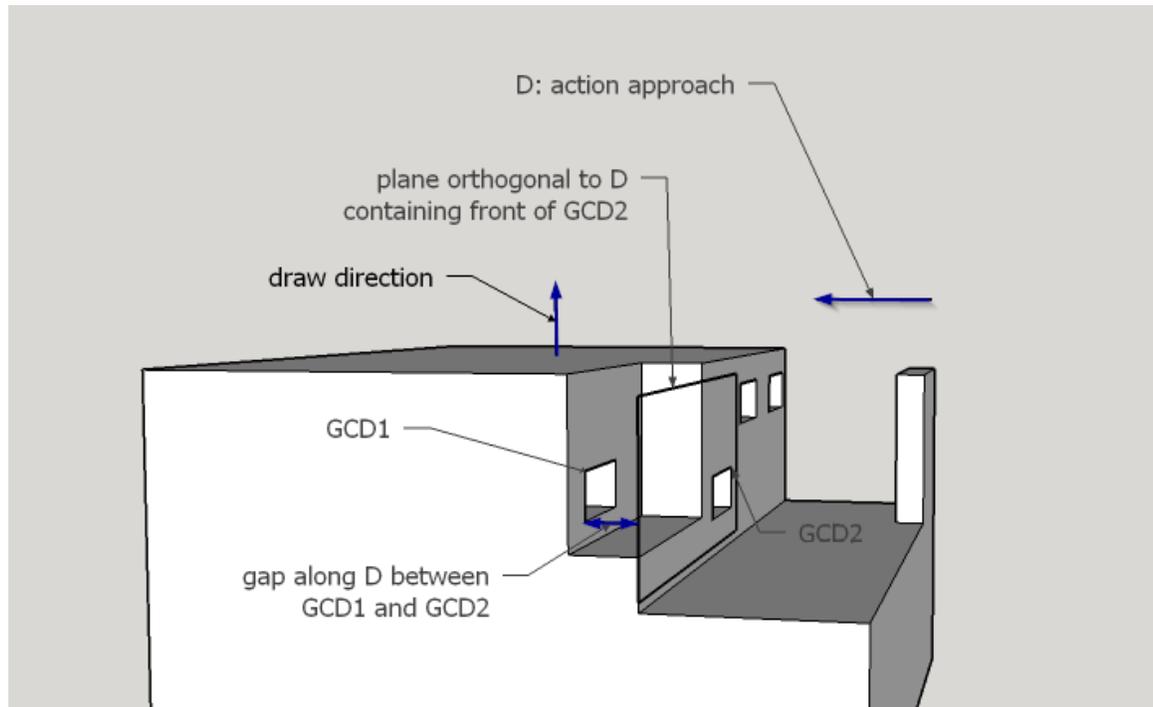
The distance between the GCD and the obstruction is the **Distance to Obstruction** property of the Is Accessible From relation whose value for **First** is the GCD and whose value for **Second** is the SetupAxis that represents D.

- Any two adjacent GCDs are sufficiently close (in the direction orthogonal to both D and the draw direction).



The cost model variable **maxGcdPitch** specifies the threshold for being sufficiently close; this value is 50.8mm in aPriori starting point VPEs.

- For any two adjacent GCDs that do not share the same volume, the distance between them along direction D is sufficiently small.



The cost model variable **maxSlideDepthPitch** specifies the threshold for being sufficiently small; this value is 25.4mm in aPriori starting point VPEs.

The distance measured is between the GCD fronts (that is, the side of the GCDs on which the slide enters).

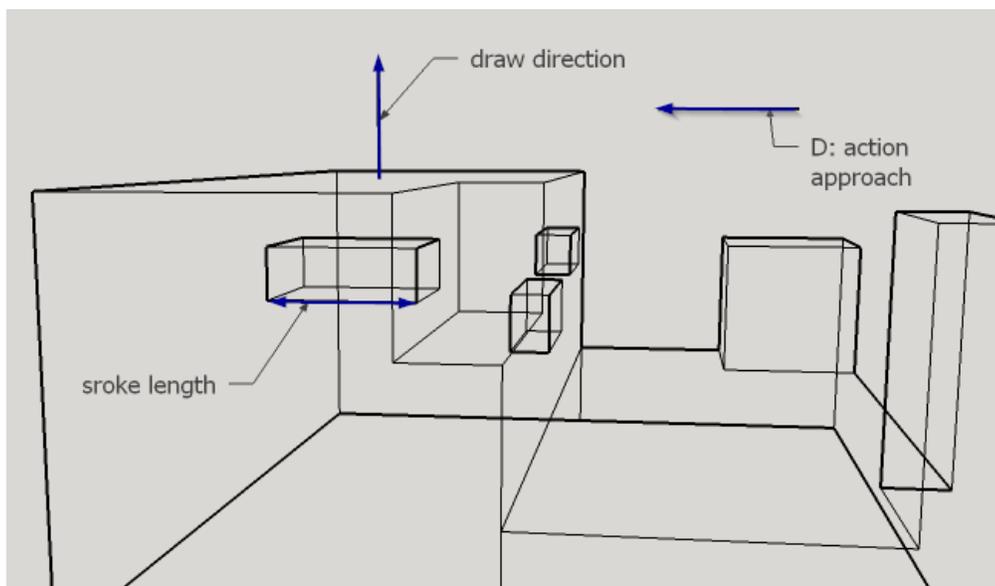
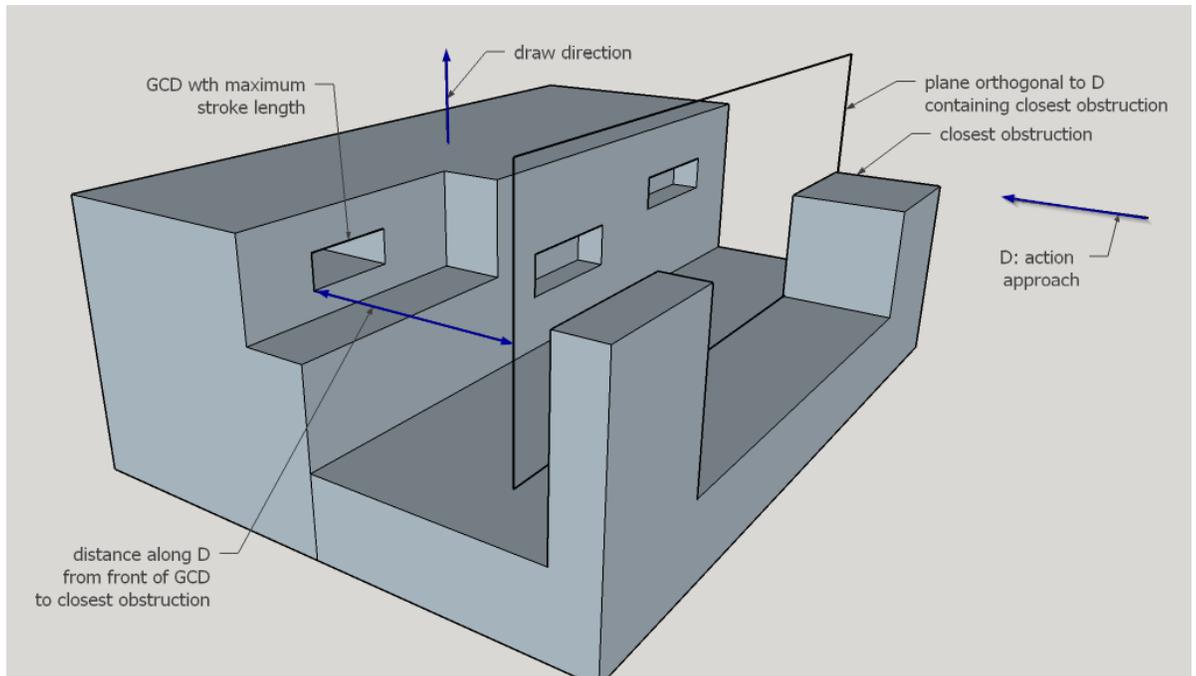
- Each GCD is sufficiently close to the part edge. That is, for each GCD, the distance from the GCD along D to the part edge is sufficiently small.

The cost model variable **maxGcdDistanceFromPartEdge** specifies the threshold for being sufficiently small; this value is 25.4mm in aPriori starting point VPEs.

There is an exception when the slide is behind another slide (that is, there is a line in direction D that intersects both the slide under consideration and some other slide closer to the part edge). In such a case, distance to part edge is ignored.

Distance to part edge is the value of the **Distance to Shadow Border** property of the Is Accessible From relation whose value for **First** is the GCD and whose value for **Second** is the SetupAxis that represents D.

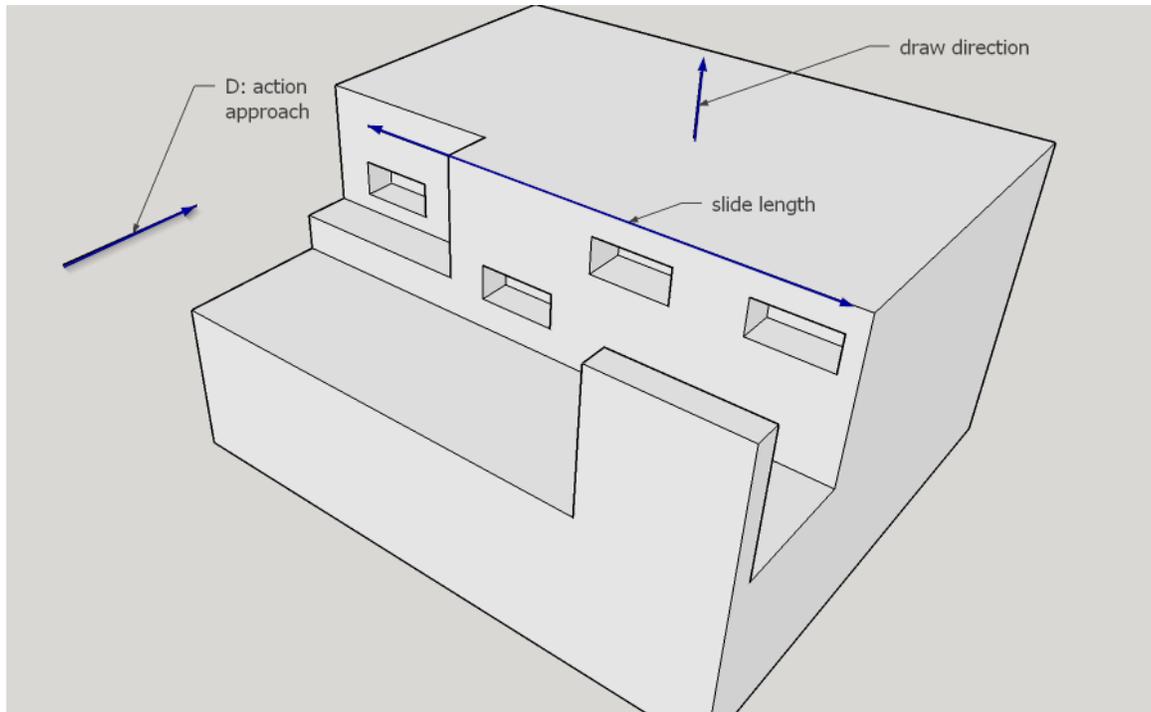
- GCDs have sufficient clearance to accommodate the slide's stroke length and avoid die lock. That is, the depth (along D) of the deepest GCD (plus some extra depth for the action base) is less than the smallest distance between a GCD and the obstruction that is closest to its associated GCD.



- All GCDs can be manufactured by a slide that does not obstruct any volume beneath the slide. The faces under a slide must not form any kind of hook; otherwise the slide would not be pullable.
- The slide is not too long (in the direction orthogonal to both D and the draw direction).

The cost model variable **maxActionLength** specifies the threshold for being too long; this value is 500mm in aPriori starting point VPEs.

Slide length is the total GCD span in the direction orthogonal to both D and the draw direction.



Lifter Bundling Criteria

aPriori's cost model assumes that an unthreaded, obscured hole or void requires a lifter only if it cannot be accommodated by a slide.

A group of GCDs can form a bundle and be handled by a single lifter only if there is a direction, D, (represented by a SetupAxis) such that all the following hold:

- All the GCDs are accessible from D.
- D is sufficiently close to orthogonal to the draw direction.

The cost model variable **drawDirectionOrthogonalEpsilonForLifters** specifies the threshold for being sufficiently close; this value is 10 degrees in aPriori starting point VPEs.

- For each GCD, if access to the GCD from D is obstructed, the obstruction is sufficiently far from the GCD.

The cost model variable **minimumLifterClearance** specifies the threshold for being sufficiently far; this value is 64.77mm in aPriori starting point VPEs.

The distance between the GCD and the obstruction is the **Distance to Obstruction** property of the Is Accessible From relation whose value for **First** is the GCD and whose value for **Second** is the SetupAxis that represents D.

- Any two adjacent GCDs are sufficiently close (in the direction orthogonal to both D and the draw direction).

The cost model variable **maxGcdPitch** specifies the threshold for being sufficiently close; this value is 50.8mm in aPriori starting point VPEs.

- For any two adjacent GCDs that do not share the same volume, the distance between them along direction D is sufficiently small.

The cost model variable **maxLifterDepthPitch** specifies the threshold for being sufficiently small; this value is 12.7mm in aPriori starting point VPEs.

The distance measured is between the GCD fronts (that is, the side of the GCDs on which the lifter enters).

- GCDs have sufficient clearance to accommodate the lifter's stroke length and avoid die lock. That is, the depth (along D) of the deepest GCD (plus some extra depth for the action base) is less than the smallest distance between a GCD and its associated obstruction (if any).
- The lifter is not too long (in the direction orthogonal to both D and the draw direction).

The cost model variable **maxActionLength** specifies the threshold for being too long; this value is 500mm in aPriori starting point VPEs.

Lifter length is the total GCD span in the direction orthogonal to both D and the draw direction.

The model costs as if a dedicated lifter handles each hole or void that is entirely *inaccessible* (because it contains an interior undercut).

Further Bundling Criteria—Breaking Ties

If multiple directions of access are appropriate for a bundle, aPriori prefers the direction that provides the smaller tool length.

If multiple directions of access providing the same tool length are appropriate for a bundle, aPriori prefers the direction that provides the smaller distance to the part edge.

If some GCD can be handled by multiple different actions of the same type, it is bundled so as to minimize the maximal width/depth gap between GCDs in each action.

Determining Action Size

Once aPriori forms the bundles, each bundle is categorized as small, medium, or large (based on the number and volume of the GCDs it contains). This helps determine the material and labor cost to produce the bundle's associated action. Labor costs take into account the cost of design, machining, assembly, and tool trade certification for each action.

Bundle size (small, medium, or large) is determined as follows:

	slides		lifters		inserts (inch ³)	grill inserts	
	standard size (inch ³)	gcd based size (mm ³)	standard size (inch ³)	gcd based size (mm ³)		standard size (inch ³)	gcd based size (inch ³)
small	75	*	75	*	1 x 1 x core plate height	32	gcd area x 2 inches
medium	1100	*	500	*	3 x 3 x core plate height	128	gcd area x 2 inches

large	2000	*	1500	*	6 x 6 x core plate height	288	gcd area x 2 inches
-------	------	---	------	---	------------------------------	-----	------------------------

* Bundle volume with approximately 1 inch added to length

Feasibility and Routing

When you choose the **Plastic Molding** process group, aPiori selects process-level routings, operation-level routings, as well as machines and materials. These procedures are described in the following sections:

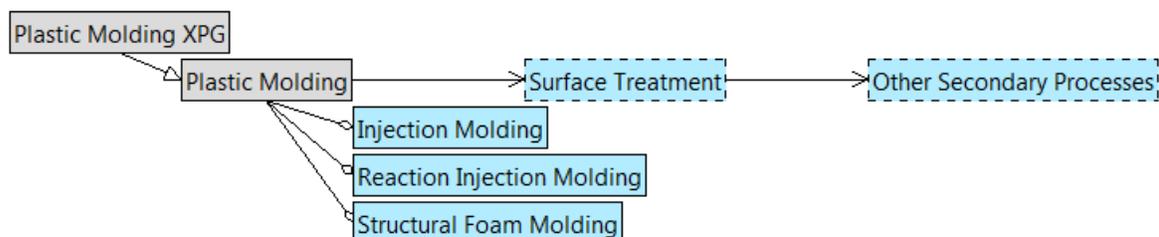
- Process-level Feasibility and Routing
- Operation-level Feasibility and Routing
- Material Feasibility and Selection
- Additional SFM Feasibility Checks
- Machine Feasibility and Selection

Process-level Feasibility and Routing

When you select the **Plastic Molding** process group, and use auto selection mode, aPiori always selects **Injection Molding** (as it is the only process in this group that aPiori auto evaluates). To manually specify a process routing, select **Edit > Routing Selection** in the Manufacturing Process pane (see also Selecting a primary process group in Manufacturing Process Information).

You can also manually select one or both of the following optional, secondary processes:

- **Surface Treatment**, which includes the following processes:
 - Shot Blast
 - Degrease
 - Painting Processes
 - Electroplating
 - Labeling
- **Other Secondary Processes (Packaging)**, including the following processes:
 - Carton Forming
 - Pack and Load
 - Carton Sealing



A plastic molding process is feasible only if all the following hold:

- Compatible material

- For SFM, compatibility of selected foaming agent (see PSO) with selected material
- Min wall thickness
- Max wall thickness

aPriori uses only one process level routing rule for IM and RIM, which checks the compatibility of the process with the material under consideration (and for SFM, . For SFM, aPriori checks for insufficient wall thickness, as well as material compatibility with both the process and the foaming agent under consideration.

Operation-level Feasibility and Routing

Below are the plastic molding operations that have associated feasibility rules, grouped by GCD type. Each operation is accompanied by necessary conditions on the GCD for the operation's feasibility. aPriori checks the operations in the order specified by the operation templates.

Combo Void

- *ComboVoidNoCore*
 - Accessible from the top or bottom, or small enough to deflect
- *ComboVoidLifter*
 - Undercut or obscured
 - Not accessible from the void direction
 - Too large to deflect
- *ComboVoidSideCore*
 - Undercut or obscured
 - Accessible from the void direction
 - Too large to deflect

Multistep Hole

- *MstepNoCore*
 - Accessible from the top or bottom
 - Not threaded
- *MstepLifter*
 - Undercut or obscured
 - Not accessible from the hole direction
- *MstepSideCore*
 - Obscured
 - Not threaded
- *MstepUnscrewMandrel*
 - Threaded

SimpleHole

- *HoleNoCore*
 - Accessible from the top or bottom, or small enough to deflect
 - Not threaded

- *HoleLifter*
 - Undercut or obscured
 - Not accessible from the hole direction
 - Too large to deflect
- *MstepSideCore*
 - Obscured
 - Too large to deflect
 - Not threaded
- *HoleUnscrewMandrel*
 - Threaded

Void

- *VoidNoCore*: This operation is feasible for a given void (that is, the void may not require a core) if both the following are true of that simple hole:
 - Accessible from the top or bottom, or small enough to deflect
- *VoidLifter*: This operation is feasible for a particular void (that is, the void requires a lifter) if all the following are true of that void:
 - Undercut or obscured
 - Not accessible from the void direction
 - Too large to deflect
- *VoidSideCore* : This operation is feasible for a particular void (that is, the void requires a slide) if all the following are true of that simple hole:
 - Undercut or obscured
 - Accessible from the void direction
 - Too large to deflect

Material Feasibility and Selection

In direct integration mode with Pro/ENGINEER, if the composition selection mode is **MCAD**, aPriori selects the MCAD composition from the part, if available. Otherwise aPriori selects the VPE default material (ABS for all baseline VPEs).

In CAD-independent mode, aPriori selects the VPE default material (ABS for all baseline VPEs).

In both direct integration and CAD-independent mode, you can either use aPriori's selection or else manually select a material composition and override the material unit cost. To manually specify a material, select **Edit > Material Selection** in the Manufacturing Process pane (see also Selecting material in Manufacturing Process Information).

Note that the process level routing rule fails with one of the following errors if you select a thermoset for IM or SFM:

- ❌ Failed because you cannot Injection Mold this type of material
- ❌ Failed because you cannot Structural Foam Mold this type of material

Similarly, if you select a thermoplastic material for RIM, the process level routing rule fails with the following error:

- ❌ Failed because you cannot Reaction Injection Mold this type of material

Two boolean-valued properties in the Material Selection table indicate which materials are feasible for which processes:

- Can_IM_SFM
- Can_RIM

Additional SFM Feasibility Checks

aPriori performs the following additional feasibility checks for structural foam molding:

- Thickness: The plant variable `minSFMWallThickness` specifies minimum wall thickness for SFM. If the current part's average thickness lies below the minimum, the following error results:
 - ❌ The average wall thickness for this part (*<average-thickness>* mm) is less than the plant limit for Structural Foam Molding (*<min-SFM-thickness>* mm)
- Valid Foaming Agent: The table below shows two columns of the Foaming Agents lookup table, which stores information on foaming agents and compatible materials. Each foaming agent is only compatible with certain materials. If the agent name is not applicable for the selected material, the process fails with the following error:
 - ❌ *<agent-name>* is not a valid foaming agent for the selected material
- Valid Foam Material: If a material is selected that does not exist in Foaming Agents lookup table (because it has *no* compatible foaming agents) the process fails with the following error:
 - ❌ *.<material-type-name>* material type does not have a compatible foaming agent

Agent Name	Material Type
Azodicarbonamide	ABS
Azodicarbonamide	PET
P-toluenesulfonylsemicarbazide	Polypropylene
Sodium bicarbonate/citric acid ester	Polystyrene
Azodicarbonamide	Polystyrene
Sodium bicarbonate/citric acid ester	ABS
5-phenyltetrazole	Polycarbonate
Sodium bicarbonate/citric acid ester	Nylon
5-phenyltetrazole	PET
P-toluenesulfonylsemicarbazide	ABS
P-toluenesulfonylsemicarbazide	Nylon
Sodium bicarbonate/citric acid ester	PET
5-phenyltetrazole	Nylon
P-toluenesulfonylsemicarbazide	Polystyrene
Azodicarbonamide	Polypropylene
Sodium bicarbonate/citric acid ester	Polypropylene

Machine Feasibility and Selection

If aPriori is configured to automatically select a machine, it selects the machine with the lowest clamp force that satisfies all the feasibility rules.

The feasibility rules require all the following:

- The mold required for the part can fit on the machine.
- The clamp force required for the part can be achieved by the machine.
- The shot size required for the part can be provided by the machine.
- The machine can open wide enough for the part to be removed.

More specifically, a machine is feasible only if all the following are true:

- Machine clamp force is greater than or equal to the required force (see [Required Clamp Force](#)).
- Required shot size (see [Required Shot Size](#)) is a sufficiently small fraction (0.75 in starting point VPEs) of the machine property **Shot Size**. VPE administrators can customize the fraction with the cost model variable **recommendedShotSizeLimitUpper**.
- Required shot size (see [Required Shot Size](#)) is a sufficiently *large* fraction of the machine property **Shot Size**. VPE administrators can customize the fraction with the cost model variable **recommendedShotSizeLimitLower** (0 in starting point VPEs).
- Horizontal machine tie bar distance is greater than or equal the horizontal dimension of the mold base.
- Vertical machine platen length is greater than or equal to the vertical dimension of the mold base. (For Injection Molding and Structural Foam Molding, if the machine property for platen length is not populated with a value, the machine property for vertical tie bar distance is used.)
- Machine maximum mold height is greater than or equal to the mold base height.
- Travel distance for mold open or close (see **Travel Distance** in [Times for Plastic Molding](#)) does not exceed the machine's **Opening Stroke**.

aPriori calculates the mold dimensions, clamp force, and shot size required for a given part based on a number of factors, including the number of cavities in the mold. The number of cavities defaults to one, but can be specified in **Process Setup Options** or calculated by aPriori. Calculation of required shot size, required clamp force, and number of cavities is described in more detail in [Required Shot Size](#), [Required Clamp Force](#), and [Number and Layout of Mold Cavities](#).

aPriori selects only from preferred machines, if there is a feasible preferred machine and the cost model variable **usePreferredMachines** is set to **true** (the default in starting point VPEs). If there is no feasible preferred machine, or if the cost model variable **usePreferredMachines** is set to **false**, aPriori selects from all machines. A machine is preferred if the machine property **isPreferred** (typically displayed as **Is Preferred**) is **true**.

To manually select a machine for a given process, select **Edit > Routing Selection** in the Manufacturing Process pane, right-click on the process in the Routing Selection window, and select **Machine Selection** from the context menu (see also [Selecting a machine for an operation in Manufacturing Process Information](#)).

Cost Algorithms and Calculations

Total injection molding costs aggregate the costs of material, labor, equipment, and tooling. Typically, tooling accounts for a significant portion of the total cost. The part's wall thickness and material (because they affect cooling time) have a significant impact on both labor and tooling costs.

This section details how costs are calculated by aPiori. Note that you can override the calculation of many of the quantities involved, and specify them explicitly—see [User Inputs for Plastic Molding](#), below.

When not otherwise specified, costs are per part.

This section is organized into the following cost categories:

- Primary Direct Costs for Plastic Molding
- Other Direct Costs for Plastic Molding
- Material Utilization for Plastic Molding
- Times for Plastic Molding
- Nominal Wall Thickness
- Required Clamp Force
- Number and Layout of Mold Cavities
- Other Calculations
- Tooling Cost

Primary Direct Costs for Plastic Molding

IM and RIM Primary Direct Costs

Material cost and direct overhead cost are calculated using the formulas below.

Material Cost = (Part Volume * Material Cost Per Volume) / Utilization

aPiori calculates the cost for material based on the following factors:

- Part volume (obtained by GCD Extraction)
- Material cost per volume (see formula below)
- Material utilization rate (see [Material Utilization](#) for Plastic Molding)

Material Cost Per Volume = Material Cost Per Mass * Material Density

Material cost per volume is the product of the following quantities:

- Material cost per mass (specified in the **Material Selection** dialog)
- Material density (listed in the **Material Selection** dialog)

Labor Cost = Labor Rate * Labor Time

Labor cost is the product of the following:

- Labor rate
- Labor time (see [Times](#) for Plastic Molding below)

SFM Primary Direct Costs

Material cost and direct overhead cost are calculated using the formulas below.

Material Cost = (Part Volume x Material Cost Per Volume x Percent Filled) / Utilization – Foam Cost Per Part

With SFM, injection *partially* fills a part's mold with material. Only after the foam expands is the mold's entire volume occupied. So aPiori calculates the cost for material based on the following factors:

- Part volume (obtained by GCD Extraction)
- Material cost per volume (see formula below)
- Percent filled (default of 0.75 specified in plant variables or user-specified value—see [User Inputs](#) for Plastic Molding)
- Material utilization rate (see [Material Utilization](#) for Plastic Molding)
- Foam Cost (see [Other Direct Costs](#) for Plastic Molding)

Material Cost Per Volume = Material Cost Per Mass x Material Density

Material cost per volume is the product of the following quantities:

- Material cost per mass (specified in the **Material Selection** dialog)
- Material density (listed in the **Material Selection** dialog)

Labor Cost = Labor Rate x Labor Time

Labor cost is the product of the following:

- Labor rate
- Labor time (see [Times](#) for Plastic Molding below)

Other Direct Costs for Plastic Molding

Additional direct costs and are calculated using the formulas below.

Additional Direct Costs = Colorant Cost x Part Rough Mass

Additional direct costs are the product of the following:

- Colorant cost (default rate of 0, user-specified rate, or standard rate—see [User Inputs](#) for Plastic Molding)
- Part rough mass (see [Material Utilization](#) for Plastic Molding, below)

Total Setup Cost Per Part = Setup Cost Per Part + Startup Scrap Cost Per Part

Total setup cost per part is the product of the following:

- Setup cost per part (see formula below)
- Startup scrap cost per part (see formula below)

Setup Cost Per Part = (Batch Setup Time / Batch Size) x (Labor Rate + Overhead Rate)

Setup cost per part is a function of the following

- Batch setup time (see [Times](#) for Plastic Molding below)
- Batch size (specified in the **Production Info** dialog)
- Labor rate
- Overhead rate

**Startup Scrap Cost Per Part =
(Sum of Per Part Material, Labor, and Overhead Cost) * Number of Scrap Parts**

Startup scrap cost per part is a function of the following:

- Per part material cost
- Labor cost (see [Primary Direct Costs](#) for Plastic Molding)
- Overhead cost
- Number of scrap parts (see formula below)

Number of Scrap Parts = Default Scrap Time / Cycle Time

Number of scrap parts is the quotient of the following:

- Default scrap time (specified in a plant variable, `scrapTimeInMinutes_IM/RIM/SFM`)
- Cycle time (see [Times](#) for Plastic Molding below)

Total Production Volume = Part Annual Volume x Part Production Life

Total production volume is the product of the following:

- Part annual volume (specified in the **Production Info** dialog)
- Part production life volume (specified in the **Production Info** dialog)

Foam Cost Per Part = Part Finish Mass * Foam Cost Per Part Mass (RFM only)

For RFM, the cost of foam per part is based on the total mass of the part (including foam) and the cost per percentage of the total mass of the part attributed to foam:

- Part Finish Mass (see [Material Utilization](#) for Plastic Molding)
- Foam Cost Per Part Mass (see [SFM Material Utilization](#))

Gets reported in Additional Direct Costs.

Material Utilization for Plastic Molding

IM Material Utilization

Material costs and utilization are determined with the help of the following formulas:

Part Rough Mass = Part Finish Mass / Utilization

Rough mass is the quotient of the following:

- Finish mass (see formula below)
- Utilization (see formula below)

Utilization = (1 – Material Waste Factor) * Mold Efficiency

Utilization depends on the following:

- Material waste factor (see formula below)
- Mold efficiency (machine property, typically 0.95)

Part Finish Mass = Part Volume * Material Density

Finish mass is the product of the following:

- Part volume (obtained from GCD extraction)
- Material density (listed in the **Material Selection** dialog)

Material Waste Factor = Runner Factor – Re grind Allowance

Material waste percentage is the difference between the following:

- Runner factor (see below)
- Re grind allowance (default of 0.25 specified in plant variables or user-specified value—see [User Inputs](#) for Plastic Molding)

Runner factor is a function of the following:

- Runner volume (see [Runner System Model](#))
- Number of cavities (see [Number and Layout of Mold Cavities](#))
- Part volume (obtained from GCD extraction)

SFM Material Utilization

Material costs and utilization are determined with the help of the following formulas:

Foam Cost Per Part Mass = (Gas Cost Per Mass * Percent Gas) + (CFA Cost Per Mass * Percent CFA)

The cost of physical gas and chemical foaming agent as a function of the total mass of the part depends on the following:

- Gas Cost Per Mass (see [User Inputs](#) for Plastic Molding)
- Percent Gas (see [User Inputs](#) for Plastic Molding)
- CFA Cost Per Mass (see [User Inputs](#) for Plastic Molding)
- Percent CFA (see [User Inputs](#) for Plastic Molding)

Default Gas and CFA costs and percentages are determined by the foaming agents lookup table's lowest cost entry for the current foaming agent (see [User Inputs](#) for Plastic Molding) and material type. If no match is available, the process will fail. If the process feasibility rules are turned off and no match is available, the cost and usage percentage are set to zero.

Part Rough Mass = Part Finish Mass / Utilization

Rough mass is the quotient of the following:

- Finish mass (see formula below)
- Utilization (see formula below)

Part Finish Mass = Part Volume * Material Density * Percent Filled

With SFM, injection *partially* fills a part's mold with material. Only after the foam expands is the mold's entire volume occupied. So finish mass is the product of the following:

- Part volume (obtained from GCD extraction)
- Material density (listed in the [Material Selection](#) dialog)
- Percent filled (default of 0.75 specified in plant variables or user-specified value—see [User Inputs](#) for Plastic Molding)

Utilization = (1 – Material Waste Factor) * Mold Efficiency

Utilization depends on the following:

- Material waste factor (see formula below)
- Mold efficiency (machine property, typically 0.95)

Material Waste Factor = Runner Factor – Regrind Allowance

Material waste percentage is the difference between the following:

- Runner factor (see below)
- Regrind allowance (default of 0.25 specified in plant variables or user-specified value—see [User Inputs for Plastic Molding](#))

Runner factor is a function of the following:

- Runner volume (see below)
- Number of cavities (see [Number and Layout of Mold Cavities](#))
- Part volume (obtained from GCD extraction)

RIM Material Utilization

Material costs and utilization are determined with the help of the following formulas:

Part Rough Mass = Part Finish Mass / Utilization

Rough mass is the quotient of the following:

- Finish mass (see formula below)
- Utilization (see formula below)

Part Finish Mass = Part Volume * Material Density

Finish mass is the product of the following:

- Part volume (obtained from GCD extraction)
- Material density (listed in the [Material Selection](#) dialog)

Utilization = (1 – Material Waste Factor) * Mold Efficiency

Utilization depends on the following:

- Material waste factor (see below)
- Mold efficiency (machine property, typically 0.95)

Material waste factor is a function of the following:

- Runner volume (see [Runner System Model](#))
- Number of cavities (see [Number and Layout of Mold Cavities](#))
- Part volume (obtained from GCD extraction)

Times for Plastic Molding

General**Labor Time = Cycle Time * Number of Operators**

Labor time is the product of the following:

- Cycle time (see formula below)
- Number of operators (specified by user or defaulted to machine property, typically 0.5—see [User Inputs for Plastic Molding](#))

Batch Setup Time

Setup Time property for the machine as defined in the VPE.

Ejection Time = Mold Open Time + Hydraulic Slide Time + Ejector Plate Time + Part Removal Time + Mold Close Time

Ejection time is the sum of the following:

- Mold open time (see formula)
- Hydraulic slide time: (see formula)
- Ejector plate time (see formula)
- Part removal time: If the setup option Part Eject Method is set to **Gravity** (the default in starting point VPEs), the part removal time is the value of the cost model variable **gravityDropTime** (1.25 seconds in starting point VPEs). Otherwise, part removal time is the value of the cost model variable **robotGrabTime** (2.5 seconds in starting point VPEs).

Mold Open Time = Travel Distance / Max Machine Velocity

Mold open time depends on the following:

- Travel distance: see Travel Distance, below.
- Max machine velocity: see formula.

Travel Distance

Travel distance for mold open or close is generally 3 or 4 times the part height:

- If the setup option Part Eject Method is set to **Gravity** (the default in starting point VPEs), the travel distance is generally the product of part height and the cost model variable **nominalHeightFactor** (3 in starting point VPEs):

$$\text{Travel Distance} = \text{Part Height} * \text{Nominal Height Factor}$$

To accommodate small parts, this value is bounded below by the product of **smallHeightPartFactor** (1.1 in starting point VPEs) and the length of the plastic forming region (PFR--see [Dimensions of the Plastic Forming Region](#)):

$$\text{Travel Distance} = \text{PFR Length} * \text{Small Height Factor}$$

In starting point VPEs, this applies when the part height is less than roughly 1/3 of the PFR length.

- If the setup option Part Eject Method is set to **Robotic**, the travel distance is generally the product of the following:
 - Part height
 - Sum of the cost model variables **nominalHeightFactor** (3 in starting point VPEs) and **roboticClearanceFactor**(1 in starting point VPEs)

$$\text{Travel Distance} = \text{Part Height} * (\text{Nominal Height Factor} + \text{Robotic Clearance Factor})$$

To accommodate small parts, this value is bounded below by the product of the following:

- Length of the plastic forming region (PFR--see [Dimensions of the Plastic Forming Region](#))
- Sum of the cost model variables **smallHeightPartFactor** (1.1 in starting point VPEs) and **roboticClearanceFactor** (1 in starting point VPEs)

$$\text{Travel Distance} = \text{PFR Length} * (\text{Small Height Factor} + \text{Robotic Clearance Factor})$$

In starting point VPEs, this applies when the part height is less than roughly 1/2 the PFR length.

See also Part Eject Method in [User Inputs for Plastic Molding](#).

$$\text{Max Machine Velocity} = \frac{(\text{Dry Cycle Stroke Factor} * \text{Max Tie Bar Distance} * 2)}{\text{Dry Cycle Time}}$$

The speed of travel during mold open and close is derived from the following:

- Dry cycle stroke factor: this is the fraction of the maximum tie bar distance that equals the stroke length. The fraction is specified by the cost model variable **dryCycleStrokeFactor** (0.7 in starting point VPEs—see the Euromap 6 technical recommendation).
- Max tie bar distance: this the larger of the machine properties **Tie Bar Distance, H** and **Tie Bar Distance, V**.
- Dry cycle time: specified by the machine property **Dry Cycle Time**.

$$\text{Hydraulic Slide Time} = (\text{Hydraulic Slide Length} / \text{Slide Cycle Rate}) * 2$$

A slide for a given undercut feature is required to be hydraulic (as opposed to mechanical) if the platen movement required to clear the mechanical slide from the undercut exceeds the mold open stroke. The presence of hydraulic slides contributes to the total ejection time because, unlike mechanical slides, hydraulic slides are retracted only after the mold is opened.

Hydraulic slide time depends on the following:

- Hydraulic slide length: this is 0 if hydraulic slides are unnecessary. If hydraulic slides are necessary, the hydraulic slide length is the maximum undercut depth plus some clearance (0.5 inch if there are multiple cavities, 5mm otherwise).
- Slide cycle rate: this is the rate at which the hydraulic slides can move, specified by the cost model variable **slideCcleRate** (100mm per second in starting point VPEs).

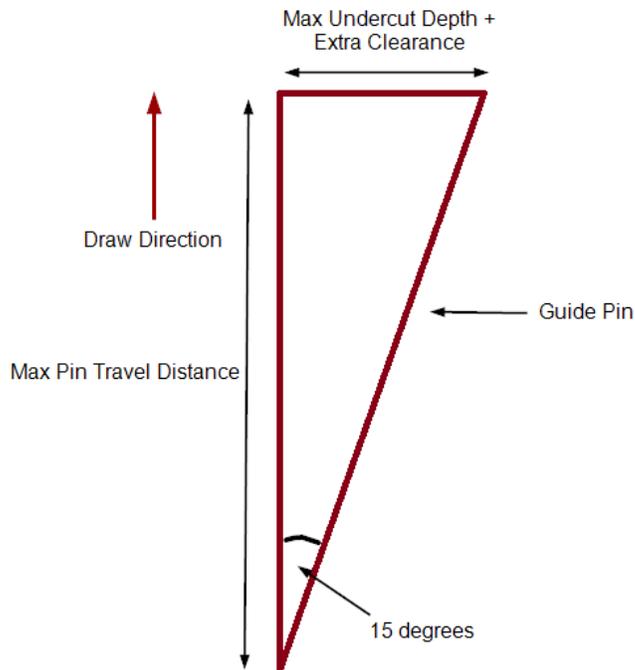
Hydraulic slides are necessary if and only if the following condition holds:

$$\text{Max Pin Travel Distance} > \text{Machine Opening Stroke}$$

Here, Machine Opening Stroke is the value of the machine property **Opening Stroke**.

Max Pin Travel Distance is the distance along the draw direction that the platen would have to travel in order to retract a mechanical slide from the part's deepest undercut. The cost model assumes that a retracting mechanical slide is guided by a pin that makes an angle of 15 degrees with the draw direction. If U is the maximum undercut depth (perpendicular to the draw direction) plus clearance (0.5 inch if there are multiple cavities, 5mm otherwise), then the required platen motion along the draw direction is $U/\tan(15)$:

$$\text{Max Pin Travel Distance} = (\text{Max Undercut Depth} + \text{Extra Clearance}) / \tan(15)$$



If the motion required for a mechanical slide (Max Pin Travel Distance) exceeds the value of the machine property **Opening Stroke**, then hydraulic slides are necessary for the part.

Ejector Plate Time = (Part Height * Ejector Distance Factor) / Max Machine Velocity

Ejector plate time depends on the following:

- Part height: determined by geometry extraction. Part height is measure along the draw direction.
- Ejector distance factor: this is the multiple of part height that equals the distance an ejector pin should move in order to eject the part. It is specified by the cost model variable **ejectorDistanceFactor** (3 in starting point VPEs).
- Max machine velocity: see formula.

Mold Close Time = Travel Distance / Max Machine Velocity

Mold close time depends on the following:

- Travel distance: see Travel Distance, above.
- Max machine velocity: see formula.

IM and SFM Times

Times such as labor time and cycle time are calculated as described below.

Cycle Time = (Injection Time + Cool Time + Ejection Time) / Number of Cavities

Cycle time is a function of the following:

- Injection time (see formula below)
- Cool time (see formula below)
- Ejection time (see formula below)

- Number of cavities (see [Number and Layout of Mold Cavities](#))

Injection Time = ((Number of Cavities * Part Volume) + Runner Volume) / Adjusted Injection Rate

Injection time is function of the following:

- Number of cavities (see [Number and Layout of Mold Cavities](#))
- Part volume (obtained from GCD extraction)
- Runner volume (see [Runner System Model](#))
- Adjusted injection rate (see formula below)

Adjusted Injection Rate = Injection Rate * Injection Rate Multiplier

Adjusted injection rate is the product of the following:

- Injection rate: specified by the machine property **Injection Rate**.
- Injection rate multiplier: specified by the cost model variable **injectionRateMultiplier** (0.25 in starting point VPEs).

Cool Time = 0 – ((Nominal Wall Thickness²) / (2 * π * Thermal Diffusivity) * ln((π/4) * (Eject Deflection Temperature – Mold Temperature) / (Melting Temperature – Mold Temperature)))

Cool time is a function of the following:

- Nominal wall thickness: see [Nominal Wall Thickness](#).
- Thermal diffusivity: see formula, below.
- Eject deflection temperature: temperature at which the part can be ejected from the mold without deformation, specified by the material property **Eject Deflection Temp**.
- Melting temperature: specified by the material property **Melting Temp**.
- Mold temperature: required temperature of the mold to support proper molten polymer flow. This is specified by the material property **Mold Temp**, increased by the amount specified by the cost model variable **defaultMoldTemperatureIncrease** (0 in starting point VPEs) or by the override specified by the user with the setup option **Local Mold Temperature Increase**—see [User Inputs for Plastic Molding](#).

Thermal Diffusivity = Thermal Conductivity / (Density of Melt * Specific Heat)

This is the thermal diffusivity of the current material, in mm²/s. The value is converted from m²/s to mm²/s so that it can be used in the Cool Time formula. The value in m²/s is determined according to this formula by using the following:

- Thermal conductivity: this is the thermal conductivity of the current material, specified in watt/m°C by the material property **Thermal Conductivity of Melt**.
- Density of melt: this is the melt density of the current material, specified in kg/m³ by the material property **Density of Melt**.
- Specific heat: this is the specific heat of the current material, specified in joule/g°C by the material property **Specific Heat of Melt**, and converted to joule/kg°C for use in this formula.

Note: Versions of aPriori prior to 2019 R2 used a value for thermal diffusivity that was provided by the material property **Thermal Diffusivity**, rather than computing it from thermal conductivity and specific heat. The cost model will continue to use the

material property **Thermal Diffusivity**, if the new material properties **Density of Melt**, **Thermal Conductivity of Melt**, and **Specific Heat of Melt** are not provided; however aPiori recommends that you update older VPEs to use the new properties, as they are reliably found on spec sheets, while thermal diffusivity generally is not.

RIM Times

Times such as labor time and cycle time are calculated as described below.

$$\text{Cycle Time} = (\text{Injection Time} + \text{Cool Time} + \text{Ejection Time} + \text{Part Handling Time} + \text{Mold-release Application Time}) / \text{Number of Cavities}$$

Cycle time is computed by default, but can be specified by the user—see [User Inputs](#) for Plastic Molding. If calculated, it is a function of the following:

- Injection time (see formula below)
- Reaction/cool time (see formula below)
- Ejection time (see formula below)
- Part handling time (based on part mass, according to the table below)
- Mold-release application time (part surface area divided by plant variable `applyMoldReleaseRate`)
- Number of cavities (see [Number and Layout of Mold Cavities](#))

Handling Time (s)	Weight (kg)
5	0.45
5	4.55
15	22.73
20	45.45
23	113.64
27	227.27
30	454,545,454.09

$$\text{Injection Time} = ((\text{Number of Cavities} \times \text{Part Volume}) + \text{Runner Volume}) / \text{Adjusted Injection Rate}$$

Injection time is function of the following:

- Number of cavities (see [Number and Layout of Mold Cavities](#))
- Part volume (obtained from GCD extraction)
- Runner volume (see [Runner System Model](#))
- Adjusted injection rate (see formula below)

$$\text{Adjusted Injection Rate} = \text{Injection Rate} * \text{Injection Rate Multiplier}$$

Adjusted injection rate is the product of the following:

- Injection rate: specified by the machine property **Injection Rate**.
- Injection rate multiplier: specified by the cost model variable `injectionRateMultiplier` (0.25 in starting point VPEs).

$$\text{Cool Time} = 0 - ((\text{Nominal Wall Thickness}^2) / (2 * \pi * \text{Material Thermal Diffusivity}) * \ln((\pi/4) * (\text{Eject Deflection Temperature} - \text{Mold Temperature}) / (\text{Melting Temperature} - \text{Mold Temperature})))$$

Cool time is a function of the following:

- Nominal wall thickness: see [Nominal Wall Thickness](#).
- Thermal diffusivity: see formula, below.

- Eject deflection temperature: temperature at which the part can be ejected from the mold without deformation, specified by the material property **Eject Deflection Temp**.
- Melting temperature: specified by the material property **Melting Temp**.
- Mold temperature: required temperature of the mold to support proper molten polymer flow. This is specified by the material property **Mold Temp**, increased by the amount specified by the cost model variable **defaultMoldTemperatureIncrease** (0 in starting point VPEs) or by the override specified by the user with the setup option Local Mold Temperature Increase—see [User Inputs for Plastic Molding](#).

Thermal Diffusivity = Thermal Conductivity / (Density of Melt * Specific Heat)

This is the thermal diffusivity of the current material, in mm²/s. The value is converted from m²/s to mm²/s so that it can be used in the Cool Time formula. The value in m²/s is determined according to this formula by using the following:

- Thermal conductivity: this is the thermal conductivity of the current material, specified in watt/m°C by the material property **Thermal Conductivity of Melt**.
- Density of melt: this is the melt density of the current material, specified in kg/m³ by the material property **Density of Melt**.
- Specific heat: this is the specific heat of the current material, specified in joule/g°C by the material property **Specific Heat of Melt**, and converted to joule/kg°C for use in this formula.

Note: Versions of aPriori prior to 2019 R2 used a value for thermal diffusivity that was provided by the material property **Thermal Diffusivity**, rather than computing it from thermal conductivity and specific heat. The cost model will continue to use the material property **Thermal Diffusivity**, if the material properties **Thermal Conductivity of Melt** and **Specific Heat of Melt** are not provided; however aPriori recommends that you update older VPEs to use the new properties, as they are reliably found on spec sheets, while thermal diffusivity generally is not.

Nominal Wall Thickness

Nominal wall thickness is calculated by default, but can be specified by the user (0.10-15.00 millimeters)—see [User Inputs for Plastic Molding](#). If calculated, the following formula is used:

$$\text{Nominal Wall Thickness} = (2 * \text{Average Wall Thickness} + \text{Maximum Wall Thickness}) * 1.25/3$$

Nominal wall thickness is a linear combination of the following:

- Part average wall thickness (obtained from GCD extraction)
- Part maximum wall thickness (obtained from GCD extraction)

This value is bounded above by part maximum thickness.

Required Shot Size

Required shot size affects machine selection (see [Machine Feasibility and Selection](#)). It is calculated with the following formula:

$$\text{Required Shot Size} = \text{Shot Size Safety Factor} * ((\text{Part Volume} * \text{Number of Mold Cavities}) + \text{Runner Volume}) * \text{Material Density} * \text{Specific Gravity}$$

Required shot size depends on the following:

- Shot size safety factor (specified by the plant variable **shotSizeSafetyFactor**)
- Part volume (obtained from GCD extraction)
- Number of cavities (see [Number and Layout of Mold Cavities](#))
- Runner volume (see [Runner System Model](#))
- Material density (specified by a material property)
- Specific gravity: this is the ratio of polystyrene density (specified by the cost model variable **densityPolystyreneForShotSize**) to the density of the current material (specified by the material property **Density**).

Required Clamp Force

Required clamp force affects machine selection (see [Machine Feasibility and Selection](#)). It is calculated with the following formula:

$$\text{Required Clamp Force} = ((\text{Part Projected Area} * \text{Number of Cavities}) + \text{Runner Area}) * \text{Injection Pressure} * \text{Clamp Safety Factor}$$

Required clamp force depends on the following factors:

- Part projected area: this is the projected area of the molded subcomponents. It is the value of the PartingLine property **projectedMoldedArea**, obtained from GCD extraction.
- Number of cavities (see [Number and Layout of Mold Cavities](#))
- Runner area (see [Runner System Model](#)).
- Injection pressure (see [Injection Pressure](#), below)
- Clamp safety factor: specified by the cost model variable **clampForceSafetyFactor** (1.1 in starting point VPEs).

Injection Pressure

Injection pressure is estimated by applying various adjustments to the material property **Injection Pressure Max**. The largest of the following is then used in the clamping force calculation:

- Adjusted pressure estimation
- Material property **Injection Pressure Min**
- Cost model variable **minInjectionPressure**

The adjustments to the material property **Injection Pressure Max** include the following:

- Adjustment by a factor that reflects whether the gating system uses hot drops. The adjustment is specified by one of the following cost model variables:
 - **hotRunnerMultiplier** (0.85 in starting point VPEs)
 - **conventionalRunnerMultiplier** (0.7 in starting point VPEs)
- Adjustment by empirically-derived factor reflecting the effect of one of the following (whichever effect dominates):

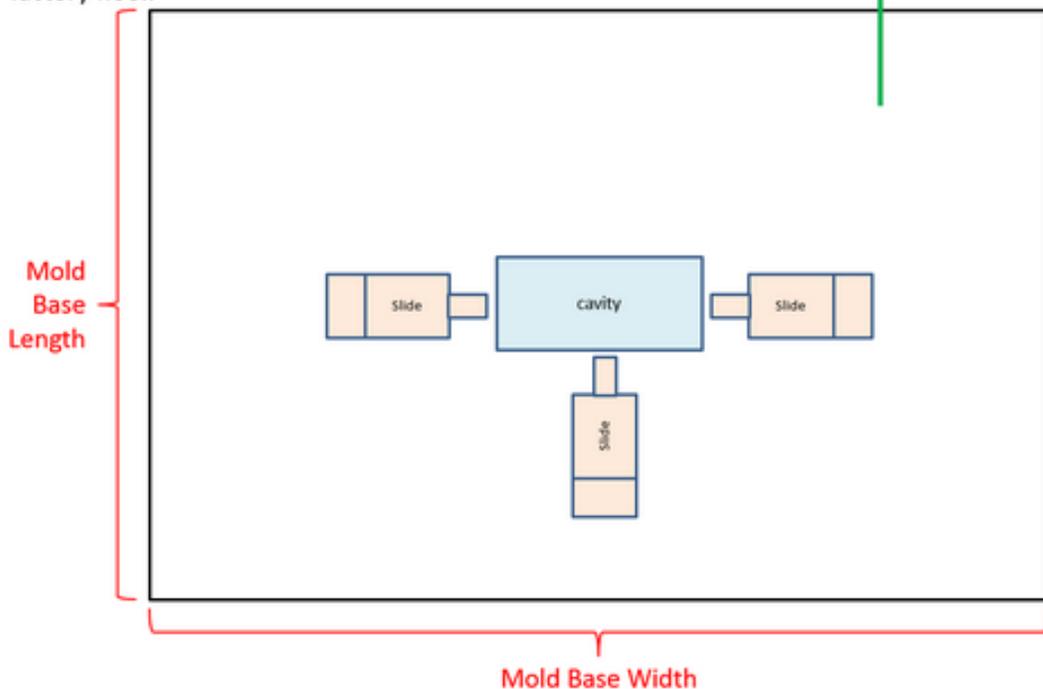
- Number of mold cavities
- Nominal wall thickness
- Cavity-length-to-nominal-wall-thickness ratio

Cavity Orientation

Cavity orientation can have an effect on machine selection, material utilization, and tooling costs, because it affects the size and dimensions of the mold base and mold runner system (see [Dimensions of the Plastic Forming Region and Runner System Model](#)).

By default, a cavity's orientation (relative to the machine platen) minimizes the effect of gravity on the action of slides. The cavity is oriented so that the motion of the majority of slides is horizontal, that is, parallel to the mold base width direction, the platen width direction, and the factory floor.

If slides exist on only 3 cavity sides, orient the cavity such that 2 of the slide actions are horizontal (parallel with the factory floor) and the 3rd slide action approaches the cavity from the direction of the factory floor.

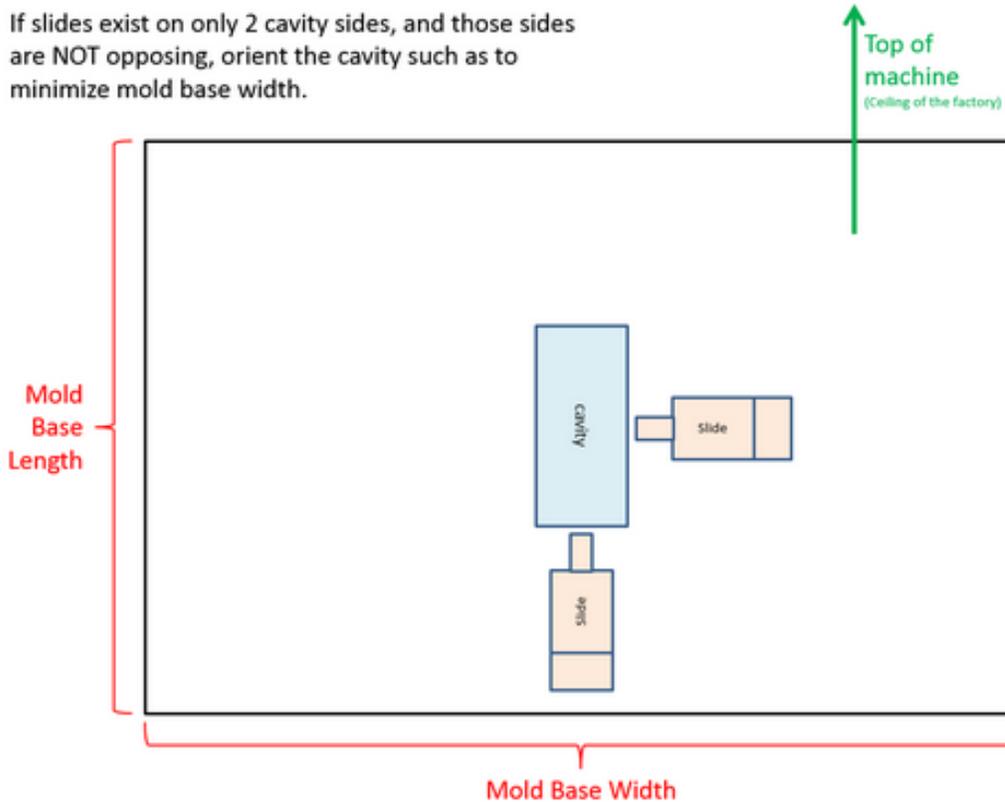


Note that in the above illustration, the draw direction is directly towards the viewer. In this case, the cavity shorter dimension (which equals part width--see [GCD Extraction for Plastic Molding](#)) is aligned with the length dimension of the machine platen and the length dimension of the mold base.

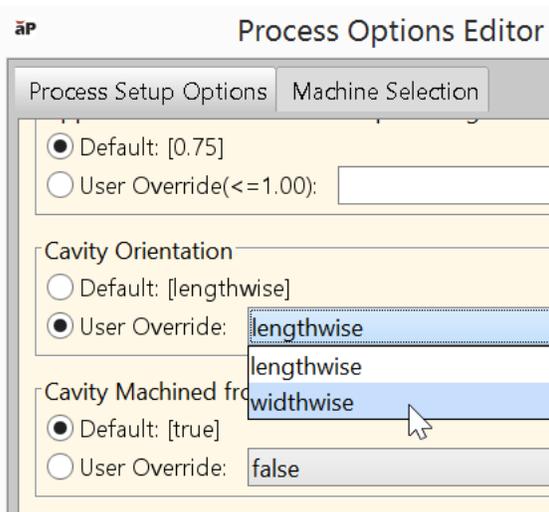
If there are no slides, or if the slide locations imply no gravitationally preferred orientation (that is, if the number of horizontally-moving slides is the same in either orientation), then by default the cavity is oriented so as to minimize mold base width, as in the illustration below. (This is also true for vertical Insert Injection Molding machines—see [Machines for](#)

Assembly Molding—since, for vertical machines, gravity is not a factor in the placement of slides.)

If slides exist on only 2 cavity sides, and those sides are NOT opposing, orient the cavity such as to minimize mold base width.



Users can override the default cavity orientation with the setup option **Cavity Orientation** (see [User Inputs for Plastic Molding](#)).



The setup option allows users to select one of the following:

- **Widthwise:** aligns the cavity shorter dimension (orthogonal to the draw direction) with the mold base length.

- **Lengthwise:** aligns the cavity longer dimension (orthogonal to the draw direction) with the mold base length.

The main Plastic Molding processes define custom outputs that specify the slide locations:

- **numSlides_North**
- **numSlides_South**
- **numSlides_East**
- **numSlides_West**

If the part is oriented so that the draw direction is towards the viewer and the parting line's length direction is to the right, then North, South, East, and West are arranged as on a map:

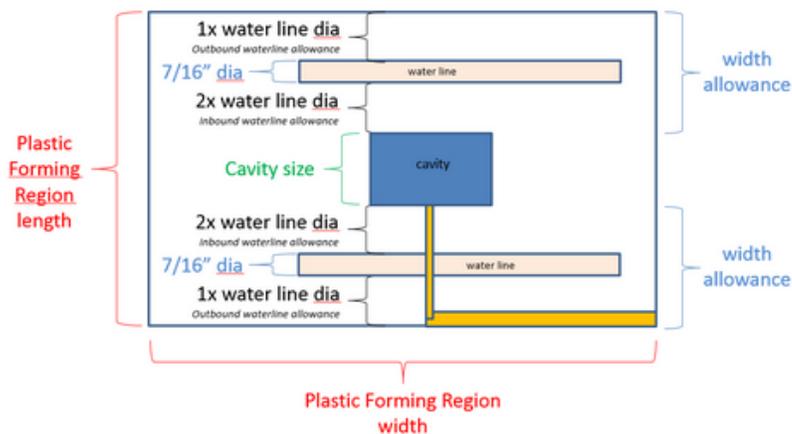
- North is the region above the part.
- South is the region below the part.
- East is the region to the right of the part.
- West is the region to the left of the part

(Note the draw direction and parting line's length direction are specified as unit vectors by the Parting Line GCD properties **Draw Direction** and **Length Direction**.)

Dimensions of the Plastic Forming Region

The plastic forming region for a mold cavity is the portion of the mold containing the mold cavity, as well as the slide mechanisms and temperature control lines required for that cavity.

Plastic Forming Region Size
With Insert



The dimensions of the plastic forming region affect mold base size as well as runner system size and layout, and so they impact machine selection, material utilization, and tooling costs.

This calculation of the dimensions of the plastic forming region depends on the following:

- Part length and width. These are determined by [GCD Extraction for Plastic Molding](#). Note the following:
 - Height dimension is always aligned with the draw direction (see [GCD Extraction for Plastic Molding](#)).
 - Length is the longer of the remaining part dimensions, and width is the shorter.
 - Part length and width have the same values as the longer and shorter dimensions of a mold cavity.
- Space allowances for the following:
 - Temperature control lines (see [Water Line Diameter](#) in [User Inputs for Plastic Molding](#))
 - Slide mechanisms (see [How aPriori Assigns Holes and Voids to Slides and Lifters](#)).
 - Inserts (see [Cavity Machined from Insert](#) in [User Inputs for Plastic Molding](#)), if any.
- [Cavity Orientation](#)

Note that the longer dimension of the plastic forming region is aligned with the platen length, and the shorter dimension of the plastic forming region is aligned with the platen width. So plastic forming region length and width are not necessarily aligned with cavity longer dimension and shorter dimension, respectively—the alignment depends on the cavity orientation.

Number and Layout of Mold Cavities

The number of mold cavities defaults to the value of the cost model variable **defaultNumCavities** (1 in starting point VPEs). The user can override the default with the setup option **Number of Cavities** (see [User Inputs for Plastic Molding](#)), and direct aPriori to do one of the following:

- Use an explicitly specified cavity count (powers of 2 between 1 and 128 inclusive).
- Calculate the number of cavities in the [Most Cost-efficient Cavity Layout](#).
- Calculate the minimum number of cavities that [Meets the Production Requirements](#) of the current scenario.

In all cases, aPriori selects a cavity layout (a rectangular array of cavities) from the lookup table **layoutNumCav**.

aP <i>layoutNumCav</i> ☒		
Cavities Length Wise	Cavities Width Wise	Coeffic
1.00	1.00	
1.00	2.00	
1.00	4.00	
1.00	8.00	
2.00	1.00	
2.00	2.00	
2.00	4.00	
2.00	8.00	
2.00	16.00	
2.00	32.00	
4.00	1.00	
4.00	2.00	
4.00	4.00	
4.00	8.00	
4.00	16.00	
4.00	32.00	
8.00	1.00	
8.00	2.00	
8.00	4.00	
8.00	8.00	

It selects a layout that is as close as square as possible, using the given number of cavities; that is, it finds a row that satisfies the following (“PFR” stands for “plastic forming region”):

- The product of the values in the columns **Cavities Lengthwise** and **Cavities Widthwise** is the given number of cavities.
- The values of **Cavities Lengthwise** and **Cavities Widthwise** minimize the difference between the mold base length and width; that is, minimize the difference between, roughly, the following quantities:
 - Cavities Lengthwise * PFR Length + Runner Region Allowance
 - Cavities Widthwise * PFR Width + Runner Region Allowance
 (The mold base dimensions are also augmented by some additional allowances related to temperature control.)

See also [Dimensions of the Plastic Forming Region](#) and [Runner System Layout](#).

Most Cost-efficient Cavity Layout

aPiori chooses the most cost-efficient number of cavities as follows:

- For each candidate cavity count (powers of 2 between 1 and 128 inclusive):
 - Select the layout that is closest to square, given the [Dimensions of the Plastic Forming Region](#).
 - Determine the fully burdened part cost using the selected layout.
- Choose the number of cavities in the layout that results in the lowest cost.

Meets the Production Requirements

Calculation of the number of cavities that can accommodate production requirements depends on the following:

- Required annual volume
- Values of the following VPE variables (starting point values shown in parentheses)
 - Production Days Per Year (253)
 - Shifts Per Day (2)
 - Hours Per Shift (8)
 - Plant Efficiency (0.95)
- Injection/cool/ejection time (estimated as 1.2 times the cool time—see [Times for Plastic Molding](#))

In the lookup table **layoutNumCav** aPriori selects the first row whose value for **Number of Cavities** is greater than or equal to the required number of cavities. In starting point VPEs, this is the smallest power of 2 (up to 128) that can meet the production requirements. (The maximum number of cavities is 128; if the required number of cavities is greater, the number of cavities is set to 128.)

Runner System Model

For plastic molded parts, aPriori models the mold runner system in order to formulate estimates of runner area and runner volume. These quantities play a key role in the following areas of the cost model:

- Machine selection (see [Machine Feasibility and Selection](#)):
 - Clamp force required of the machine depends in part on area occupied by the runner system in a mold cross section (parallel to the parting plane). See [Required Clamp Force](#).
 - Shot size required of the machine depends in part on runner system volume. See [Required Shot Size](#).
- Material utilization and material cost. See [Material Utilization for Plastic Molding](#).
- Injection time (which affects cycle time). See [Times for Plastic Molding](#).

Note that runner system volume is 0 if hot drops are used (see [User Inputs for Plastic Molding](#)).

The following sections further describe the runner system model:

- [Runner System Calculation Overview](#)
- [Runner System Layout](#)
- [Runner System Volume and Area](#)

Runner System Calculation Overview

The cost model calculates runner system area and volume based primarily on properties of the *runner system layout*. In particular, the calculation is based primarily on properties of the straight runner segments (referred to as “branches”) that form the paths from the sprue to the cavities:

- Number of cavities fed by each branch
- Length of each branch relative to various quantities (such as the dimensions of the cavity, sprue, and plastic forming region)
- Diameter of the smallest runner branches (branches that feed a single cavity)

The runner layout is chosen based on the following:

- Cavity layout
- Gate location (see [User Inputs for Plastic Molding](#))
- Cavity orientation

The choice of cavity layout, in turn, depends on the number of cavities and the dimensions of the plastic forming region for a single cavity. See [Number and Layout of Mold Cavities](#) for more information.

The plastic forming region for a mold cavity is the portion of the mold containing the mold cavity, as well as the slide mechanisms and temperature control lines that are required for that cavity. The calculation of its dimensions depends on the following:

- Part length and width
- Space allowances for temperature control lines and slide mechanisms, and for inserts
- Cavity orientation

See [Dimensions of the Plastic Forming Region](#) for more information.

By default, the cavity is oriented so that the motion of the majority of slides is horizontal. A setup option allows the user to specify the orientation explicitly. See [Cavity Orientation](#) for more information.

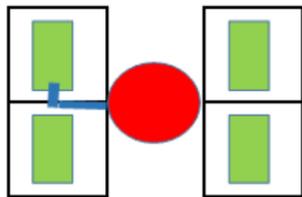
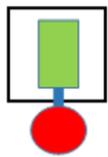
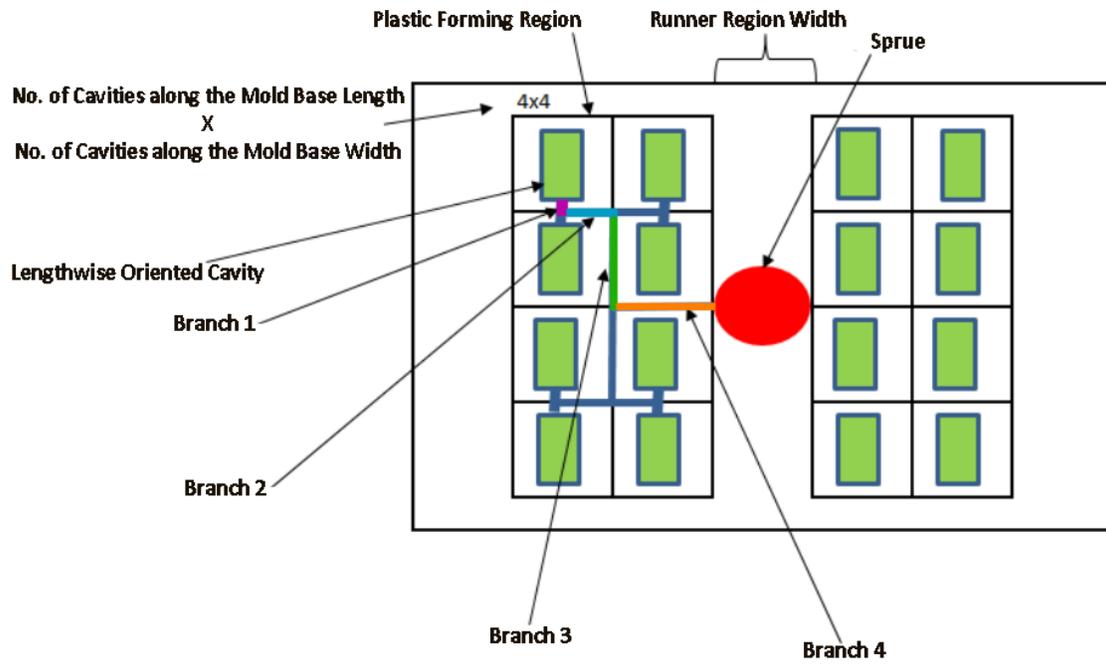
See [Runner System Layout](#) and [Runner System Volume and Area](#) for more detailed information on the runner system model.

Runner System Layout

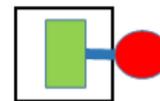
In the course of costing a part, the cost model chooses one of large number of candidate runner system layouts. The runner system is made up of a network of straight runner segments (branches) within the mold that provide paths of flow from the sprue to each cavity.

Information about each possible layout is encoded by the cost model in lookup tables and CSL vectors. (See the *Cost Model Workbench User Guide* for information on CSL.) This includes information about the cavity layout, as well as the number of runner branches in each path from sprue to cavity, and the number of cavities fed by each branch. It also includes information about the length of each branch relative to various quantities, such as the dimensions of the sprue and plastic forming region.

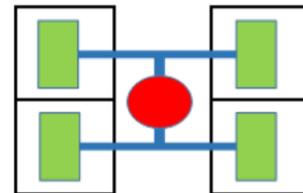
The following illustrations show a few examples of the various candidate layouts. The first one is annotated and serves as a key for the others. Note that most diagrams show only some of the paths from the sprue to a cavity.

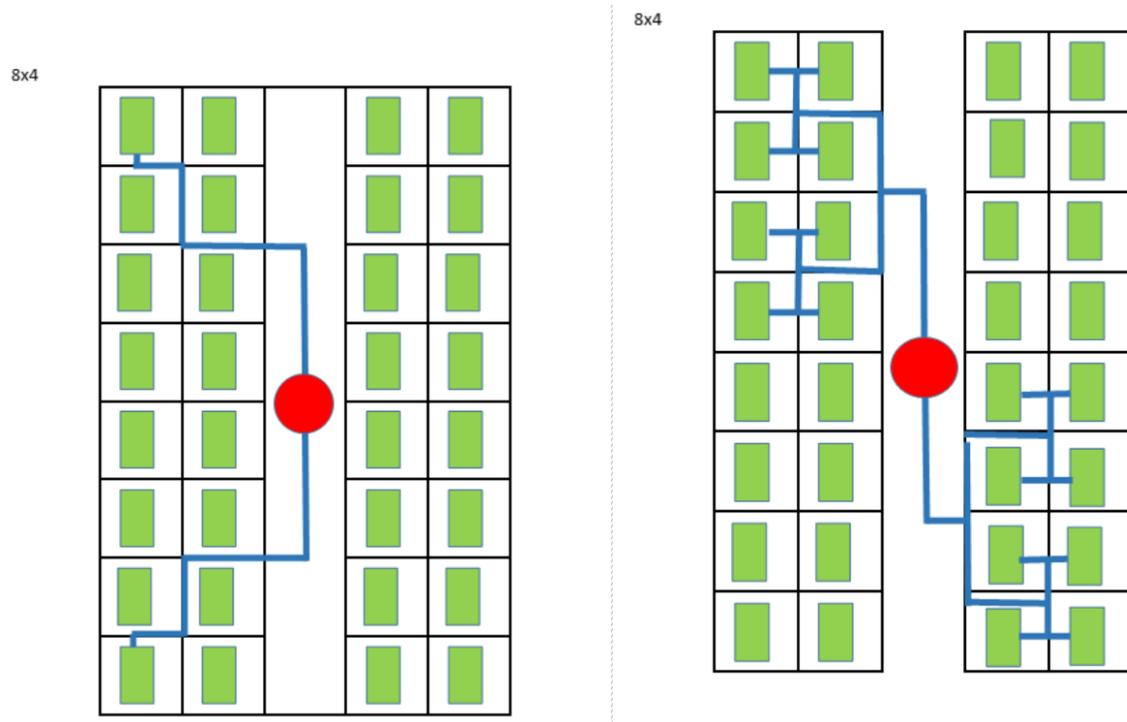


1x1



2x2





All these layouts show lengthwise-oriented cavities (see [Cavity Orientation](#)). There are similar layouts for widthwise cavities as well—see the discussion of equivalences below.

The cost model assumes that each runner network has the following properties:

- The network provides, for each cavity, a path from the sprue to that cavity's gate. Note that some of the branches of a given path are branches of other paths as well, and so feed multiple cavities.
- By convention, the various branches of a given path are ordered and designated as follows:
 - The *1st branch* is the branch that directly feeds the cavity.
 - The *last branch* is the branch that is fed directly by the sprue.
 - For any i between 1 and the number of branches in a path, the i^{th} branch of the path is the branch that is a distance of i branches from the cavity; that is, it is the branch that has $i-1$ branches between it and the cavity.
- The system is balanced, that is, all the paths have the same form, in the following sense: For any two paths, p_1 and p_2 , from the sprue to a gate
 - p_1 and p_2 have the same number of branches.
 - For every i between 1 and the number of branches, the i^{th} branch of p_1 has the same length and diameter as the i^{th} branch of p_2 .
- The diameter of runner branches increases as the number of cavities they feed increases. In particular, the cross-sectional area of a branch is the product of the number of cavities the branch feeds and the cross-sectional area of the 1^{st} branch of a path. So, for example, the cross-sectional area of a runner branch that feeds two cavities is twice that of a branch that feeds one cavity. (These diameters are bounded above by a cost model variable—see the formula for Diameter of an i^{th} Branch in [Runner System Volume and Area](#).)

Note that, for any i , the number of i^{th} branches in the whole runner system is the total number of gates divided by the number of gates fed by a single i^{th} branch.

Each candidate runner layout is represented by the following data structures:

- Row in the lookup table **tblRunnerCalculationCoefficients**, which, effectively, represents the number of cavities fed by each branch.
- Vector in CSL, which represents branch lengths in terms of sprue, plastic forming region, and runner region dimensions.

The cost model chooses the runner layout that corresponds to the following characteristics:

- Cavity layout (see [Number and Layout of Mold Cavities](#)). In **tblRunnerCalculationCoefficients**, the cavity layout is specified in the column **Mold Layout Column**. The values in this column have the following form:

number of cavities along the mold base length X number of cavities along the mold base width

For each entry in this table, *number of cavities along the mold base length* \geq *number of cavities along the mold base width*. This means that the only cavity layouts that are explicitly listed in the table are those with at least as many cavities along the mold base length as along the mold base width.

For cavity layouts with more cavities along the mold base width than along the mold base length, an entry for an *equivalent* runner system is used. See below for an explanation of equivalences among runner system layouts.
- Cavity orientation (see [Cavity Orientation](#)): in **tblRunnerCalculationCoefficients**, the cavity orientation is specified (along with gate location—see below) in the column **Cav Orientation and Runner Attachment Side**.
- Gate location (see [User Inputs for Plastic Molding](#)): indicates whether the gate is on the long side (length) or short side (width) of a cavity. In **tblRunnerCalculationCoefficients**, the gate location is specified (along with cavity orientation) in the column **Cav Orientation and Runner Attachment Side**.

Layout Description	Cav Orientation And Runner Attachment Side	Cavity Number	Mold Layout Column	N
artificial	LengthwiseLongsideOrWidthwiseShortside	4.00	4x1	
artificial	LengthwiseLongsideOrWidthwiseShortside	8.00	8x1	
artificial	LengthwiseLongsideOrWidthwiseShortside	16.00	8x2	
artificial	LengthwiseLongsideOrWidthwiseShortside	32.00	16x2	
artificial	LengthwiseLongsideOrWidthwiseShortside	64.00	16x4	
artificial	LengthwiseLongsideOrWidthwiseShortside	64.00	32x2	
artificial	LengthwiseLongsideOrWidthwiseShortside	128.00	32x4	
artificial	LengthwiseShortsideOrWidthwiseLongside	4.00	4x1	
artificial	LengthwiseShortsideOrWidthwiseLongside	8.00	8x1	
artificial	LengthwiseShortsideOrWidthwiseLongside	16.00	8x2	
artificial	LengthwiseShortsideOrWidthwiseLongside	32.00	16x2	
artificial	LengthwiseShortsideOrWidthwiseLongside	64.00	16x4	
artificial	LengthwiseShortsideOrWidthwiseLongside	64.00	32x2	
artificial	LengthwiseShortsideOrWidthwiseLongside	128.00	32x4	
natural	LengthwiseLongsideOrWidthwiseShortside	2.00	2x1	
natural	LengthwiseLongsideOrWidthwiseShortside	4.00	2x2	
natural	LengthwiseLongsideOrWidthwiseShortside	8.00	4x2	

In this table, each row actually represents multiple equivalent runner layouts. There are two types of runner layout equivalence. Two runner systems are equivalent if either of the following holds:

- The two runner layouts have the same cavity layout, but differ with regard to both cavity orientation and gate location. Here is an example:



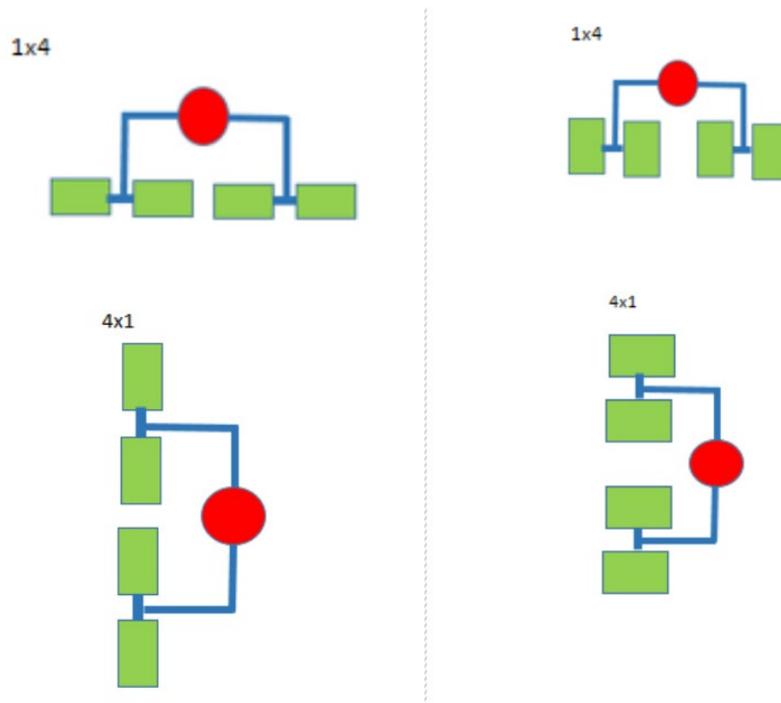
Such layouts are just the same with regard to the number of branches in each path, and with regard to the number of cavities fed by each branch, but are different with regard to branch lengths. So they are the same with regard to the information stored in the lookup table. Branch lengths are represented separately, in CSL vectors.

The following table shows equivalencies for runner layouts that have the same cavity layout:

Cavity Orientation	Gate Location	Is equivalent to	Cavity Orientation	Gate Location
Lengthwise	Long Side		Widthwise	Short Side
Lengthwise	Short Side		Widthwise	Long Side

- Rotational Equivalence: the two runner layouts differ only with regard to overall rotational orientation. Each runner layout with an $n \times m$ cavity layout is a rotation

of some runner layout with an $m \times n$ cavity layout, and is therefore equivalent for the purposes of runner area and volume calculation. Here are some examples:



In the figure above, the two runner systems on the left are equivalent to one another:

Top left runner layout:

- 1X4 cavity layout
- Widthwise cavity orientation
- Short side gate

Bottom left runner layout:

- 4X1 cavity layout
- Lengthwise cavity orientation
- Short side gate

Similarly, the two runner systems on the right are equivalent to one another:

Top right runner layout:

- 1X4 cavity layout
- Lengthwise cavity orientation
- long side gate

Bottom right runner layout:

- 4X1 cavity layout
- Widthwise cavity orientation
- Long side gate

Here is the list of rotational equivalences:

Cav Orientation and Runner Attachment Side	Mold Layout	Is equivalent to	Cav Orientation and Runner Attachment Side	Mold Layout
WidthwiseShortSide	$n \times m$		LengthwiseShortSide	$m \times n$
WidthwiseLongSide	$n \times m$		LengthwiseLongSide	$m \times n$

Runner System Volume and Area

The volume of the runner system is given by the following formula:

$$\text{Runner System Volume} = \text{Runner Volume} + \text{Sprue Volume} + \text{Pin Point Gate Volume}$$

This is the volume of the entire runner system, including the sprue and gates. It is the sum of the following:

- Runner volume. Runners are assumed to be cylindrical with multiple branches, with a diameter for a given branch that depends on the number of cavities fed by that branch. See formula.
- Sprue volume: assumes a cylindrical sprue with
 - Diameter equal to the diameter of a *last* runner branch (see [Runner System Layout](#)). See also the formula below for Diameter of an i^{th} Branch.
 - Height: calculated based on part height, water line diameter, and the value of the cost model variable **defaultOutboundWaterlineMultiplier**.
- Pin point gate volume: not applied for edge gating. See formula.

Note that runner system volume is 0 if hot drops are used (see [User Inputs for Plastic Molding](#)).

$$\text{Pin Point Gate Volume} = \text{Pin Point Gate Length} * \text{Pin Point Gate Cross-sectional Area} * \text{Number of Cavities}$$

Not applied for edge gating. This value is based on the assumption that each cavity's gate is cylindrical. It is the product of the following:

- Pin point gate length: this is the difference between the mold base height and the part height.
- Pin point gate cross-sectional area: calculated based on a gate diameter that is 25% greater than the part's maximum thickness (bounded below by the value of the cost model variable **minRunnerDiameter**—2.032mm in starting point VPEs).
- Number of cavities (see [Number and Layout of Mold Cavities](#))

$$\text{Runner Volume} = \sum_{i=1}^{i=\# \text{ of segments per path}} \text{Volume of all } i^{\text{th}} \text{ Branches}$$

This is the volume of the runner system, not including the sprue and gates. It is the sum of the volumes of all the runner branches (see [Runner System Layout](#)). The sum is performed by grouping the branches by distance from a cavity (where distance is the count of branches along the path of flow). All the branches in such a group have the same length and diameter. See the formula below.

**Volume of all i^{th} Branches = Number of i^{th} Branches *
Cross-sectional Area of an i^{th} Branch * Length of an i^{th} Branch**

This is the total volume of all branches that are at a distance of i branches from a cavity (along the path of flow). All such branches feed the same number of cavities and have the same length and diameter. See [Runner System Layout](#) for more information. The total volume of all i^{th} branches is the product of the following:

- Number of i^{th} branches (see below)
- Cross-sectional area of an i^{th} branch (see formula)
- Length of each i^{th} branch (see below)

Runner System Area = Runner Area + Pin Point Gate Area

This is the area of the projection of the runner system onto the parting plane. It is the sum of the following:

- Runner Area (see formula)
- Pin point gate area (see formula)

Note that runner system area is 0 if hot drops are used (see [User Inputs for Plastic Molding](#)).

Pin Point Gate Area = Pin Point Gate Cross-sectional Area * Number of Cavities

Pin point gate area is 0 if the setup option **Gating Type for Cold Runner System** is **Edge** (see [User Inputs for Plastic Molding](#)). Otherwise, it is the product of the following:

- Pin point gate cross-sectional area: calculated based on a gate diameter that is 25% greater than the part's maximum thickness (bounded below by the value of the cost model variable **minRunnerDiameter**—2.032mm in starting point VPEs).
- Number of cavities (see [Number and Layout of Mold Cavities](#))

Runner Area = $\sum_{i=1}^{i=\# \text{ of segments per path}}$ Area of all i^{th} Branches

This is the area of the projection of the runners on the parting plane. It is the sum of the areas of all the runner branches (see [Runner System Layout](#)). The sum is performed by grouping the branches by distance from a cavity (where distance is the count of branches along the path of flow). All the branches in such a group have the same length and diameter. See the formula below.

**Area of all i^{th} branches = Number of i^{th} Branches *
Diameter of an i^{th} Branch * Length of an i^{th} Branch**

This is the total area of the rectangular cross-sections of all branches that are at a distance of i branches from a cavity (along the path of flow). All such branches feed the same number of cavities and have the same length and diameter. See [Runner System Layout](#) for more information. The total area of all i^{th} branches is the product of the following:

- Number of i^{th} branches (see below)
- Diameter of an i^{th} branch (see formula)
- Length of each i^{th} branch (see below)

Number of i^{th} Branches

The number of i^{th} branches in any runner system layout is the total number of cavities divided by the number of cavities fed by a single i^{th} branch. This quotient is stored in the lookup table **tblRunnerCalculationCoefficients**. The row representing the current runner layout is looked up by all the following:

- Cavity layout (see [Number and Layout of Mold Cavities](#))
- Cavity orientation (see [Cavity Orientation](#))
- Edge Gate location (see [User Inputs for Plastic Molding](#))

In that row, the number of i^{th} branches is the value in the column **Branch*i***.

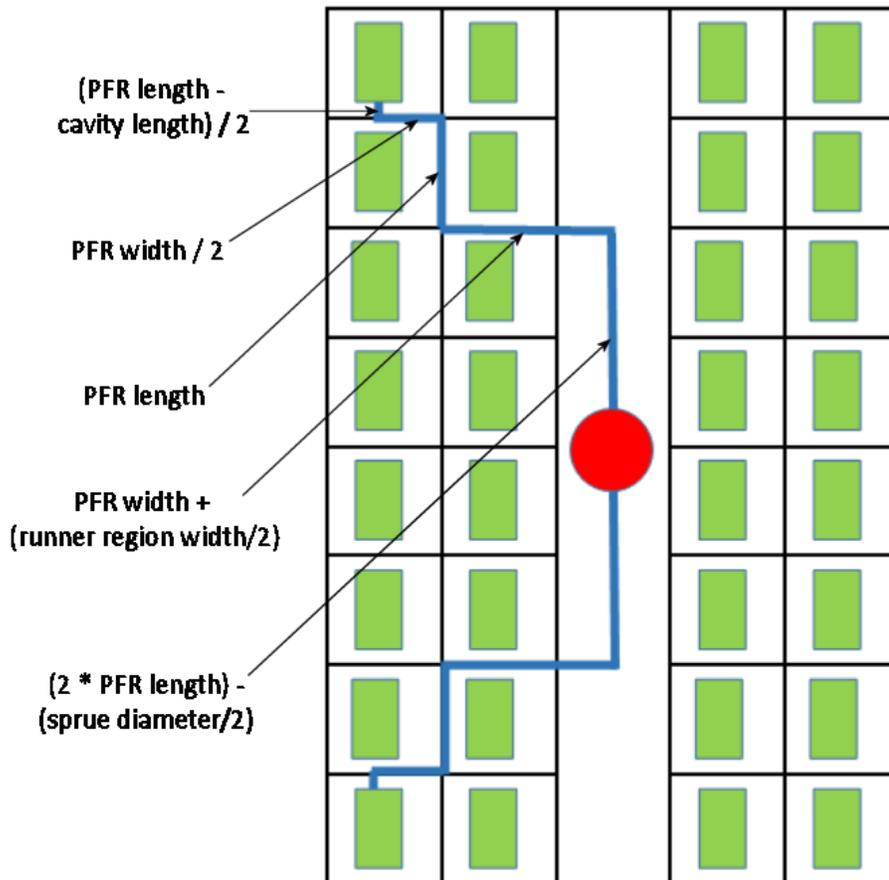
See [Runner System Layout](#) for more information.

Length of Each i^{th} Branch

This is calculated based on the following:

- CSL vector that is associated with the current runner system layout, which represents branch lengths relative to sprue, plastic forming region, and runner region dimensions. See [Runner System Layout](#).
- Sprue outside diameter: specified by the cost model variable **sprueClearanceDia** (38.1mm in starting point VPEs).
- Plastic forming region dimensions (see [Dimensions of the Plastic Forming Region](#))
- Cavity dimensions
- Runner region width: this is the width of the region of a multi-cavity mold that contains the sprue. Its length runs either the entire length of the mold or the entire width of the mold (see [Runner System Layout](#)). Its width is the same as the sprue diameter.

The illustration below shows some sample of runner length calculations. Note that “PFR” stands for “plastic forming region”:



Runner region width is the same as the sprue diameter.

Note that for single-cavity molds with **Center gating** (see **Gating Type for Cold Runner System** in **User Inputs for Plastic Molding**), the length of the only runner branch is the product of the following:

- Twice the value of the cost model variable **runnerRetentionTab** (4.7625mm in starting point VPEs)
- 25% greater than the part's **Max Thickness** (bounded below by the value of the cost model variable **minRunnerDia**—2.032mm in starting point VPEs)

Cross-sectional Area of Each i^{th} Branch = $\pi * (\text{Diameter of an } i^{\text{th}} \text{ Branch} / 2)^2$

The cross-sectional area of an i^{th} runner branch is calculated based on its diameter. See the formula below for the calculation of the diameter of an i^{th} branch.

Diameter an i^{th} Branch = Diameter Coefficient for i^{th} Branches * Diameter of a 1st Branch

The diameter of an i^{th} runner branch is generally the product of the following:

- Diameter coefficient for i^{th} branches: this value is contained in the **Diameter Coeff Branch- i** column of the lookup table **tblRunnerCalculationCoefficients**. The row representing the current runner layout is looked up by all the following:
 - Cavity layout (see **Number and Layout of Mold Cavities**)
 - Cavity orientation (see **Cavity Orientation**)

- Edge Gate location (see [User Inputs for Plastic Molding](#))

The diameter coefficient is the square root of the number of cavities fed by that branch. This is the factor by which the diameter of a branch must be increased over the diameter of a single-cavity branch (since the number of cavities fed is the factor by which the cross-sectional area must be increased). See [Runner System Layout](#) for more information.

- Diameter of a 1st branch: this is 25% greater than the part's **Max Thickness** (bounded below by the value of the cost model variable **minRunnerDia**—2.032mm in starting point VPEs).

The diameter of an *j*th branch is bounded above by the cross-sectional area of a runner with diameter **maxRunnerDia** (12.7mm in starting point VPEs).

Other Calculations

Tooling cost payback per part is calculated with the following formula:

$$\text{Tooling Cost Payback Per Part} = \frac{\text{Hard Tooling Cost}}{(\text{Part Annual Volume} \times \text{Components Per Product} \times \text{Payback Period})}$$

Tooling cost payback per part depends on the following:

- Hard tooling cost (see [Tooling Cost](#))
- Part annual volume
- Components per product
- Payback period (either default plant variable or part production life)

Tooling Cost

Tooling cost appears as **Hard Tooling Cost** in the cost taxonomy under Capital Costs.

Tooling cost depends on factors in the following areas:

- [Tool Life for Plastic Molding](#)
- [Tooling-relevant Part GCDs](#)
- [Mold Material Costs](#)
- [Purchased Mold Component Costs](#)
- [Tooling Labor Costs](#)
- [Miscellaneous Tooling Costs](#)

Tool Life for Plastic Molding

The tooling model estimates the number of parts that can be produced with a given tool before it wears to the point that it needs to be replaced. Based on that estimate, the cost model determines the number of tools required to manufacture the production volume specified in the Production Scenario tab of the Cost Guide, and accounts for that number of tools in total hard tooling cost.

Tool-life estimation is based on part material, and adjusted for tool material and tool coating type, as follows:

- 4 To determine an unadjusted value for the number of shots that can be endured by a single tool, the cost model looks up this number by part material in the lookup table **tblToolLife**.

Material Type	Num Shots Per Tool
ABS	144,000
Acetal	278,000
Acrylic	257,000
Nylon	278,000
PBT	144,000
PET	428,000
Polycarbonate	144,000
Polypropylene	321,000
Polystyrene	428,000
Polyurethane	144,000
PPS	144,000

- 5 This value is then multiplied by the number of mold cavities (see [Number and Layout of Mold Cavities](#)), yielding the unadjusted number of parts that can be produced by a single mold.
- 6 The result is then adjusted for mold material by multiplying it by the tool shop property **Tool Life Factor** for the current mold material (see the setup option **Mold Material** in [User Inputs for Plastic Molding](#)).
- 7 That result is then adjusted for mold coating by multiplying it by the **Tool Life Improvement Factor** looked up lookup in the table **tblToolCoating** by coating type (see the setup option **Plating of the Mold** in [User Inputs for Plastic Molding](#)).

Coating Cost Factor (USD / kg)	Coating Type	Tool Life Improvement Factor
0.00	None	1.00
1.90	Tribo-coating	1.10
2.80	Electroless Nickel	1.40
3.50	Electroless Teflon	1.70
4.10	Nitrided Steel	1.90
4.40	Electroplated Chromium	2.00
6.90	Plasma Sprayed	3.00
18.20	PVD TiN	7.20
19.10	CVC TiC	7.50
26.60	DuplexVariantic	14.40

For a given costing, either the formula Dependencies or Investment tab displays the number of tools assumed by tooling cost calculations.

Tooling-relevant Part GCDs

Tooling costs are affected by the following information obtained from GCD extraction:

- Number of simple holes considered Sleeve Pins (that is, simple holes for which the property `sleevePinHole` is `true`)
- Number of surfaces
- Number of small, medium, or large grill inserts (set by comparing GCD child artifacts for which the property `isGrill` is `true`, to established area size constraints)
- Number of ribs (set by the property `isRib`)

Mold Material Costs

Following are material costs whose values are specified in toolshop:

- Core and cavity plate material type and rate
- Ejector box material type and rate
- Actions material type and rate
- EDM carbon

SFM and RIM use less expensive mold material, by default, than IM.

Note: Core and cavity plate material costs are 0 with a standard (as opposed to custom) mold base. By default in starting point VPEs, a standard mold base is used—see the setup option Mold Construction Method in [User Inputs](#) for Plastic Molding.

Purchased Mold Component Costs

The following are among the plant variables whose values specify costs of purchased mold components:

- `leaderPinsShoulderBushings`
- `returnPinsShoulderBushings`
- `ejectorGuidePinsBushings`
- `locatingRings`
- `sprueBushing`
- `stopPins`
- `sideLocks`
- `socketHeadCapScrewsShort`
- `socketHeadCapScrewsLong`
- `supportPillars`
- `sleevePins`
- `limitSwitches`
- `ejectorPins`
- `waterManifolds`
- `waterManifoldFittings`
- `waterHoses`
- `quickHoseDisconnects`
- `waterBaffles`

Tooling Labor Costs

Labor rates for the following are specified in toolshop:

- Machining:

- CNC machining time and EDM machining time per cavity/core, die block, and action/cam, etc.
- Deep hole or gun drilling time for water cooling lines
- Assembly
- Design:
 - 3D CAD modeling, mold flow, etc.
 - NC programming time per cavity/core, die blocks, actions/cams, etc.
- Finishing/polishing
- Spotting
- Tryout
- CMM inspection

CNC Machining Versus EDM Burning

Some mold components are created with CNC machining only, some mold components are created with EDM burning only, and some mold components are created with a combination of CNC machining and EDM burning.

The cost model assumes the following:

- Only CNC machining is used to create the following components:
 - Mold cavity
 - Mold core
- Only EDM Burning is used to create sleeve pins.
- Both CNC machining and EDM burning are used to create the following components:
 - Speaker grill inserts
 - Rib inserts & insert pockets
 - Lifters & lifter pockets
 - Slides & slide pockets

Labor Costs for Mold Items Created with CNC Machining

Labor costs for CNC machining are based on CNC setup time and item machining time. Following are the mold items created by CNC machining, together with the factors that contribute to machining time:

Cavity & core machining time is the sum of the following

- Cavity & core volume * time per unit volume * number of cavities
- Part surface area * time per unit area * number of cavities
- Runoff area * time per unit area
- Speaker grill volume * time per unit volume * number of cavities
- Total insert volume * time per unit volume * number of cavities
- Total insert pocket volume * time per unit volume * number of cavities

Actions machining time is the sum of the following:

- Total lifter volume * time per unit volume * number of cavities
- Total slide volume * time per unit volume * number of cavities

Labor Costs for Mold Items Created with EDM Burning

Labor costs for EDM burning are based on electrode design time as well as CNC setup and machining time for electrodes.

Electrode design depends on the number of the following features:

- Grill inserts
- Side cores
- Lifters
- Inserts (major, medium, minor)

CNC setup and machining time for the creation of electrodes is determined as follows:

- Setup time is 0.25 hours per electrode. The number of electrodes is the sum of the following:
 - Total side cores * number of burns per side core
 - Total lifters * number of burns per lifter
 - Total major inserts * number of burns per major insert
 - Total medium inserts * number of burns per medium insert
 - Total minor inserts * number of burns per minor insert
 - Total sleeve pins * number of burns per sleeve pin
 - Total speaker grills * number of burns per speaker grill
- Machining time is 0.003 hours per electrode unit volume. The total electrode volume is determined as follows:
 - Slide electrode volume * total side cores * number of burns per side core
 - Lifter electrode volume * total lifters * number of burns per lifter
 - Major insert electrode volume * total major inserts * number of burns per major insert
 - Medium insert electrode volume * total medium inserts * number of burns per medium insert
 - Minor insert electrode volume * total minor inserts * number of burns per minor insert
 - Sleeve pin electrode volume * total sleeve pins * number of burns per sleeve pin
 - Speaker grill electrode volume * total speaker grills * number of burns per speaker grill

This part of the cost model assumes a maximum of 4 side cores. It also assumes the following regarding the number of burns per feature:

- Side cores: 3 burns each
- Lifters: 2 burns each
- Major inserts: 4 burns each
- Medium inserts: 3 burns each
- Minor inserts: 2 burns each
- Sleeve pins: 2 burns each
- Speaker grills: 3 burns each

Miscellaneous Tooling Costs

Costs for the following also affect tooling costs:

- Heat treatment (rate specified in toolshop. Multiplied by sum of weights for core plates, cavity plates, inserts, and actions.)
- Plating (default plant variable for nitride plating. Multipliers set for all other plating types)
- Stress relief (default rate specified in toolshop)
- Texture (default plant variable for coarse texture. Multipliers set for all other textures)
- Freight (default rate specified in toolshop)
- Markup/profit (default rate specified in toolshop)

User Inputs for Plastic Molding

You can control the values listed below by modifying **Process Setup Options**, plant variables, or toolshop variables.

To access **Process Setup Options** for a given process, right click the process in the Manufacturing Process pane, and select **Process Setup Options** from the context menu.

See [Process Defaults and Thresholds](#) for more information on plant variables.

Follow these steps to access toolshop variables for a given VPE and process:

- 1 select **Tools > VPE Toolset** and click the **VPE Manager** button in the VPE Toolset window.
- 2 Double click the desired VPE in the Select VPE window
- 3 In the VPE manager, click + to expand the **Plastic Molding** process group, and then click + to expand **Processes**.
- 4 Click + to expand the desired process, click + to expand **Tool Shops**, and then select **Default**.

The following process setup options affect overall cost:

- **Number of Operators:** affects the calculation of labor time and labor cost--see [Primary Direct Costs](#) for Plastic Molding and [Times](#) for Plastic Molding. **Process Setup Options** provide the following alternatives:
 - Default value (typically 0.5, specified as the machine property `Labor Ratio`)
 - User-defined value
- **Colorant:** affects **Addition Direct Costs** in the cost taxonomy—see [Other Direct Costs](#) for Plastic Molding. **Process Setup Options** provide the following alternatives:
 - No colorant (default)
 - Colorant at standard rate (0.75 USD/kg, specified as a plant variable)
 - Colorant at user-defined color charge
- **Material Regrind Allowance:** affects material utilization--see [Material Utilization](#) for Plastic Molding. **Process Setup Options** provide the following alternatives:
 - Default value (0.25, specified as a plant variable)

- User-defined value
- **Part Eject Method:** By default in starting point VPEs, the part eject method is **Gravity**. You can customize the default with the cost model variable **gravityEject**. You can override the default on a part-by-part basis with this setup option. Specify **Gravity** or **Robotic**. The eject method affects part removal time, as well as mold open and close time. See [Times for Plastic Molding](#).
- **Local Mold Temperature Increase:** specifies an amount by which to increase the mold temperature for the purpose of calculating cool time--see [Times for Plastic Molding](#). This can be used to account for localized temperature increases in mold regions that cannot accommodate cooling channels (for example, regions with closely-spaced ribs). Cooling channels are typically at least 6 mm in diameter.

By default, this increase is 0. Administrators can customize the default increase (0) with the plant variable **defaultMoldTemperatureIncrease**. You can override the default on a part-by-part basis with this setup option.
- **Nominal Wall Thickness:** affects calculated cooling time—see [Times for Plastic Molding](#). **Process Setup Options** provide the following alternatives:
 - Value derived from GCDs (default--see [Times for Plastic Molding](#))
 - User-defined value

The following affect SFM material utilization (see [Material Utilization](#) for Plastic Molding):

- **Percent of Mold Filled: Process Setup Options** provide the following alternatives:
 - Default percentage (0.75, specified as a plant variable)
 - User-defined value (0.60-1.00)
- **Foaming Agent: Process Setup Options** provide the following alternatives:
 - Default agent (p-Toluenesulfonyl semicarbazide)
 - User-specified agent
- **Percent of Chemical Foaming Agent Used: Process Setup Options** provide the following alternatives:
 - Default percentage (0.005, specified in the foaming agent lookup table)
 - User-defined value (0.000-0.250)
- **Chemical Foaming Agent Cost: Process Setup Options** provide the following alternatives:
 - Default cost (0.04 USD/kg, specified in the foaming agent lookup table)
 - User-defined value (≥ 0.00 USD/kg)
- **Percent of Physical Gas Used: Process Setup Options** provide the following alternatives:
 - Default percentage (0.00)
 - User-defined value (0.00-0.25)
- **Physical Gas Cost: Process Setup Options** provide the following alternatives:
 - Default cost (< 0.01 USD/kg)
 - User-defined value (≥ 0.00 USD/kg)

The following values affect tooling costs (see [Tooling Cost](#)). They are listed together with their associated process setup options:

- **Number of Cavities**
 - Default value of 1

- Cost-efficient
- Value derived from annual volume for single mold (see [Number and Layout of Mold Cavities](#))
- User-defined value (1-256)
- **Number of Hot Drops** (per cavity)
 - Default value (0)
 - User-defined number of standard hot drops
 - User-defined number of Sequential Valve Gates (SVG) hot drops
- **Tolerances**
 - High tolerance: +/- 0.051 mm (+/- 0.002")
 - Medium tolerance (default): +/- 0.127 mm (+/- 0.005")
 - Low tolerance: +/- 0.254 mm (+/- 0.010")
- **Cavity Finish**
 - 300 stone
 - 600 stone (default)
 - 320 grit paper
 - 600 grit paper
 - SPI A-3
 - SPI A-2
 - SPI A-1
- **Number of Plates in Mold**
 - 2-plate mold
 - 3-plate mold
- **Parting Line Complexity**
 - Flat
 - Non-flat
- **Plating of the Mold**
 - None
 - Nickel
 - Nitride
 - Chrome
 - Teflon
 - Tribo-Coating
- **Cavity Texture**
 - None
 - Fine-shallow
 - Moderate-medium
 - Coarse-deep
- **Heat Treating of Mold**
 - Yes
 - No
- **Stress Relief Mold**

- Yes
- No
- **Mold Material** (core and cavity plates)
 - P20 Tool Steel
 - H13 Tool Steel
 - Stainless Steel
 - Carbon Steel
 - Aluminum
 - Epoxy
- **Material for the Actions**
 - P20 Tool Steel
 - H13 Tool Steel
 - Stainless Steel
 - Carbon Steel
 - Aluminum
- **Ejector Box Material**
 - P20 Tool Steel
 - H13 Tool Steel
 - Stainless Steel
 - Carbon Steel
 - Aluminum
- **EDM Electrode Material**
 - Carbon
 - Copper
- **Freight Rate**
 - Default VPE rate (toolshop variable)
 - User-defined value
- **Import Duty Rate**
 - Default VPE rate (toolshop variable)
 - User-defined value
- **SG&A Rate**
 - Default VPE percent (toolshop variable)
 - User-defined value
- **Markup and/or Profit Rate**
 - Default VPE rate (toolshop variable)
 - User-defined value
- **Mold Construction Method**

By default in starting point VPEs, a standard mold base is used. VPE administrators can customize the default with the cost model variable **defaultMoldConstruction**. You can override the default with this setup option.

 - Standard mold base
 - Custom mold base

The following options affect mold design. They affect tooling costs, material cost and utilization, and machine selection.

- **Lower recommended shot size percentage limit**

This places a lower limit on the fraction of barrel capacity used for a shot.

- Default: specified by the cost model variable **recommendedShotSizeLimitLower** (0 in starting point VPEs).
- Override: enter a value between 0 and 1.

- **Upper recommended shot size percentage limit**

This places an upper limit on the fraction of barrel capacity used for a shot.

- Default: specified by the cost model variable **recommendedShotSizeLimitUpper** (0.75 in starting point VPEs).
- Override: enter a value between 0 and 1.

- **Edge Gate Location:**

This specifies the side of the cavity to which the runner is attached (long side or short side). Changing the runner attachment side can increase or decrease the runner length.

- Default: specified by the cost model variable **defaultRunnerAttachmentSide** (**long** in starting point VPEs.).
- Override: select **Long** or **Short**.

- **Cavity Orientation:**

This specifies how the cavity is oriented with respect to the mold base. Changing the cavity orientation can affect machine, selection, material utilization, and tooling cost, because it can affect mold base and runner size. See [Cavity Orientation](#) for more information.

- Default: lengthwise, that is, the length of the cavity is aligned with the length of the mold base.
- Override: select **lengthwise** to align the cavity length with the mold base length or **widthwise** to align the cavity width with the mold base length.

- **Cavity Machined from Insert**

This specifies whether the cavity and water line channels are drilled directly into the solid mold base, or into smaller inserts which then are placed into the solid mold base. Spacing allowances are affected by this choice. By default, whether inserts are assumed is governed by one of the following:

- Cost model variable **defaultEnablePlasticFormingRegionInserts** (if the cost model variable **defaultInsertMethod** is **SPECIFY**)
- Lookup by number of mold cycles (annual production volume divided by number of cavities) in the lookup table **tblSpiType** (otherwise).

Users can override the default with this setup option. Select **true** or **false**.

- **Gating Type for Cold Runner System**

Changing between edge and center gating can decrease or increase the runner length.

- Default, specified by the cost model variable **defaultGatingType** (**Edge** in starting point VPEs).

- Override: select **Edge** or **Center**.
- **Water Line Diameter**
This specifies the diameter of the water line used for temperature control.
 - Default: specified by the cost model variable **defaultWaterLineDiameter** (8mm in starting point VPEs).
 - Override: Select a value from the dropdown list (6, 8, 10, or 12 millimeters).
- **Use Overhanging Clamping Plates**
This specifies whether the mold base uses clamping plates that hang over the mold's other plates (cavity and core plates). By default in starting point VPEs, the clamping plates are flush with the mold's other plates. VPE administrators can customize the default with the cost model variable **defaultEnableOverhangingClampingPlates** (**false** in starting point VPEs). Users can override the default on a per-part basis with this setup option.

Use of overhanging clamping plates increases tooling cost, and may result in selection of a larger machine than would be selected with flush clamping plates in use.

The following setup options also affect tooling design and cost, and in some cases override values derived from geometry extraction:

- **Number of Small/Medium/Large Slides or Side Cores**
- **Number of Small/Medium/Large Lifters**
- **Number of Unscrewing Mechanisms** (to relieve threads)
- **Number of Small/Medium/Large Inserts**
- **Number of Small/Medium/Large Speaker Grill Inserts**
- **Mold Base Size – Length**
- **Mold Base Size – Width**
- **Cavity Plate Height**
- **Core Plate Height**

Process Defaults and Thresholds

The table below lists some of the important plant variables, together with default values and descriptions.

Follow these steps to access plant variables for a given VPE and process:

- 1 select **Tools > VPE Toolset**, and then click the **Cost Model Workbench** button in the VPE Toolset window.
- 2 Click **+** to expand the desired VPE in the Open Cost Model window, and then double click the **Plastic Molding** process group.
- 3 In the Cost Model Workbench, click **+** to expand **Global Cost Model Information**, and then double click **Cost Model Variables**.

Variable	Value	Unit Type	Units	Description
----------	-------	-----------	-------	-------------

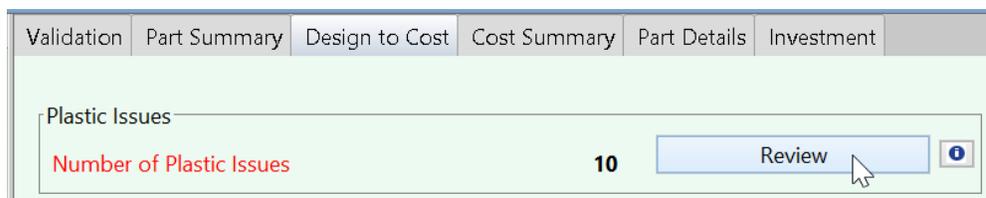
betweenPartsMoldBorder150T	38.1	Length	millimeter	Spacing between parts in the mold if press tonnage is less than 150 tons.
betweenPartsMoldBorder300T	50.8	Length	millimeter	Spacing between parts in the mold if press tonnage is less than or equal to 300 tons.
betweenPartsMoldBorder500T	76.2	Length	millimeter	Spacing between parts in the mold if press tonnage is greater than 300 tons.
defaultMoldConstruction	'Standard Mold Base'			'Standard Mold Base' versus 'Custom Mold Base' as the default for the VPE. (Tooling cost driver)
defaultNumTryOuts	3			Default number of tryouts. (Tooling Cost Driver)
defaultPercentGas	0			Default usage percentage by part weight for physical gas. Only applicable for Structural Foam Molding. User may override via Process Setup Options.
defaultRegrindAllowance	0.25			Default allowable percentage of runners and scrap allowed with virgin material. (Material cost driver)
minSFMWallThickness	3	Length	millimeter	Minimum part wall thickness feasibility threshold for the Structural Foam Molding process.
percentFilled	0.75			Percentage of the mold that is initially filled before foam expansion occurs. Only applicable for Structural Foam Molding. User may override via Process Setup Options.
scrapTimeInMinutes_IM	15	Time	minute	Initial setup time for Injection Molding where parts are assumed to be scrap. Determine the setup cost per part.
scrapTimeInMinutes_RIM	30	Time	minute	Initial setup time for Reaction Injection Molding where parts are assumed to be scrap. Determine the setup cost per part.
scrapTimeInMinutes_SFM	30	Time	minute	Initial setup time for Structural Foam Molding where parts are assumed to be scrap. Determine the setup cost per part.
sleevePinAspectRatioLimit	8			Threshold at which the ratio of wall height to diameter of a curved wall will necessitate a sleeve pin. (Tooling cost driver)
sleevePinLimitDia	4	Length	millimeter	Threshold at which the diameter of a curved wall will necessitate a sleeve pin. (Tooling cost driver)

timePerTryoutBase	12	Time	hour	Basic time per tryout for clamp force under 500 tons. (Tooling cost driver)
clampForceSafetyFactor	1.1			Multiplier of clamp pressure required to ensure that the machine is capable of applying the necessary mold pressure.
densityPolystyreneForShotSize	1020	Density	kilogram / millimeter ³	Industry standard density of polystyrene used to define shot size in grams.
edgeMoldBorderX1500T	178	Length	millimeter	Edge mold border in X direction for press force under 1500 tons.
edgeMoldBorderX150T	140	Length	millimeter	Edge mold border in X direction for press force under 150 tons.
edgeMoldBorderX300T	165	Length	millimeter	Edge mold border in X direction for press force under 300 tons.
edgeMoldBorderX500T	190	Length	millimeter	Edge mold border in X direction for press force under 500 tons.
edgeMoldBorderXGreater1500T	140	Length	millimeter	Edge mold border in X direction for press force over 1500 tons.
edgeMoldBorderY1000T	165	Length	millimeter	Edge mold border in Y direction for press force under 1000 tons.
edgeMoldBorderY200T	152	Length	millimeter	Edge mold border in Y direction for press force under 200 tons.
edgeMoldBorderY30T	90	Length	millimeter	Edge mold border in Y direction for press force under 30 tons.
edgeMoldBorderYGreater1000T	140	Length	millimeter	Edge mold border in Y direction for press force over 1000 tons.
largeInsertArea	36	Area	inch ^ 2	Standard 6" x 6" area of a large insert. Used to calculate the insert volume of a large rib.
largeLifterVolume	1500	Volume	inch ^ 3	Standard volume of a large lifter. Used to calculate the total volume of a large lifter bundle.
largeSlideVolume	2000	Volume	inch ^ 3	Standard volume of a large slide. Used to calculate the total volume of a large slide bundle.
mediumInsertArea	9	Area	inch ^ 2	Standard 3" x 3" area of a medium insert. Used to calculate the insert volume of a medium rib.
mediumLifterBundleWidthThreshold	127	Length	millimeter	Width threshold between a medium and large lifter bundle (based on 5 inches).
mediumLifterVolume	500	Volume	inch ^ 3	Standard volume of a medium lifter. Used to calculate the total volume of a medium lifter bundle.

mediumSlideBundleWidthThreshold	304.8	Length	millimeter	Width threshold between a medium and large slide bundle (based on 12 inches).
mediumSlideVolume	1100	Volume	inch ^ 3	Standard volume of a medium slide. Used to calculate the total volume of a medium slide bundle.
shotSizeSafetyFactor	1.02			Multplier of required shot size to account for material left in chamber. Used to calculate the required shot size.
smallInsertArea	1	Area	inch ^ 2	Standard 1" x 1" area of a small insert. Used to calculate the insert volume of a small rib.
smallLifterBundleWidthThreshold	76.2	Length	millimeter	Width threshold between a small and medium lifter bundle (based on 3 inches).
smallLifterVolume	75	Volume	inch ^ 3	Standard volume of a small lifter. Used to calculate the total volume of a small lifter bundle.
smallSlideBundleWidthThreshold	76.2	Length	millimeter	Width threshold between a small and medium slide bundle (based on 3 inches).
smallSlideVolume	75	Volume	inch ^ 3	Standard volume of a small slide. Used to calculate the total volume of a small slide bundle.

Design-to-cost Configuration for Plastic Molding

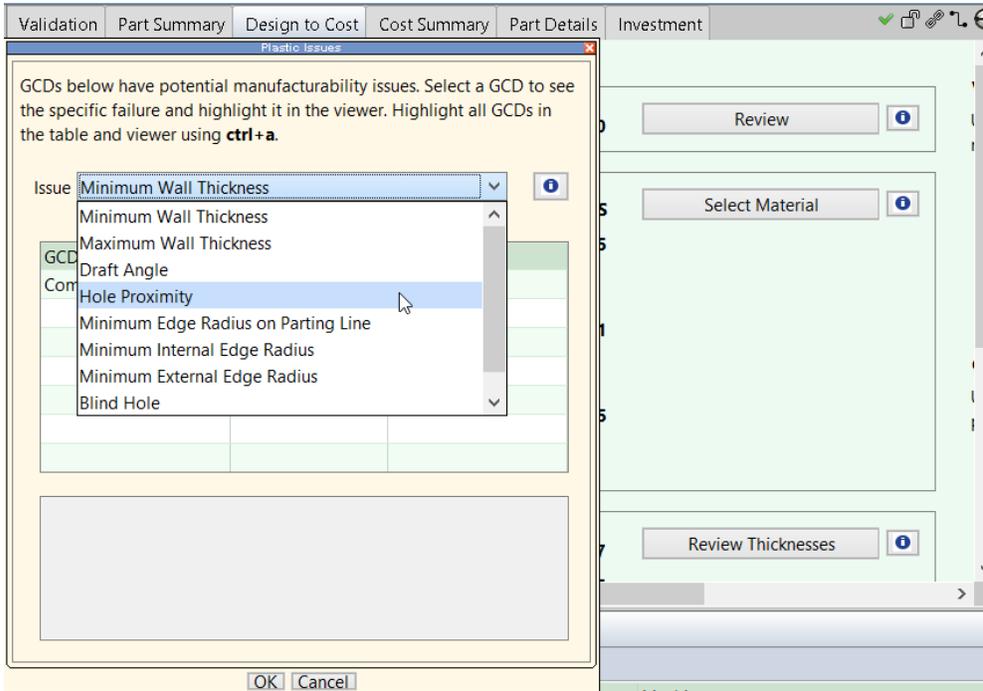
This section covers configuring Design to Cost for the Plastic Molding process group. You can configure some of the thresholds that help determine what plastic Issues and thickness violations are listed in the Design to Cost tab.



The following sections cover lookup tables that specify thresholds related to plastic issues (Material Issues, Draft Issues, Proximity Issues, Radus Issues, Hole Issues):

- Material Issues: Wall Thickness Thresholds
- Draft Issues: Draft Angle Thresholds
- Radius Issues: Minimum Internal and External Edge Radius
- Proximity Issues: Hole Proximity Issues

▪ Hole Issues: Length-to-diameter (L/D) Ratio



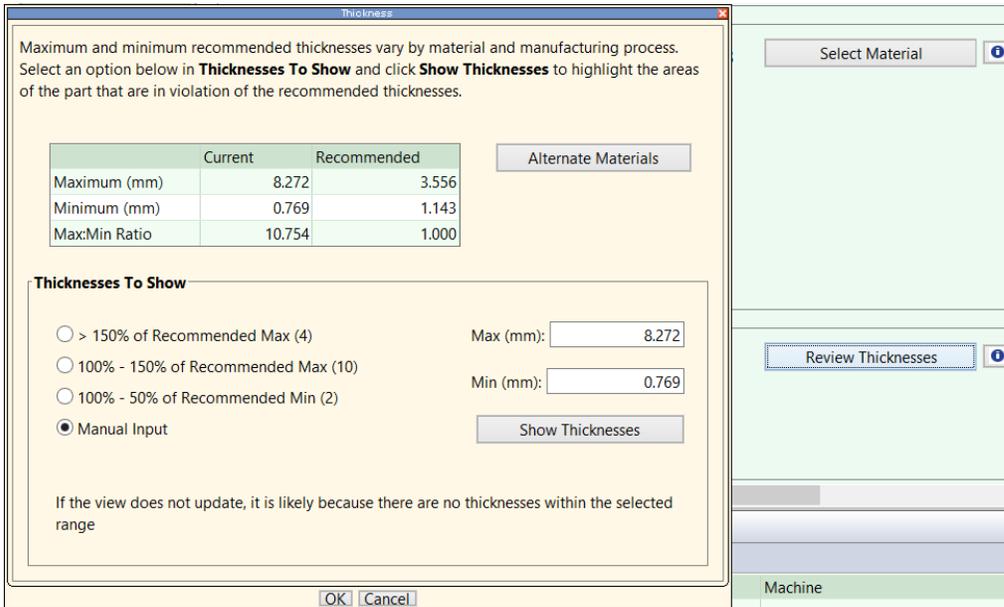
Material Issues: Wall Thickness Thresholds

The lookup table **tblWallThickness** specifies the recommended minimum and maximum wall thickness for each process and material.

Material Type	Maximum Wall Thickness (mm)	Minimum Wall Thickness (mm)	Process Name
ABS	3.56	1.14	Injection Molding
ABS	15.00	2.03	Structural Foam Molding
Acetal	3.05	0.76	Injection Molding
Acetal	15.00	2.03	Structural Foam Molding
Nylon	2.92	0.76	Injection Molding
Nylon	15.00	2.03	Structural Foam Molding
Nylon	50.80	1.52	Reaction Injection Molding
PET	5.08	0.76	Injection Molding
PET	15.00	2.03	Structural Foam Molding
Polycarbonate	3.81	1.02	Injection Molding
Polycarbonate	15.00	2.03	Structural Foam Molding
Polypropylene	3.81	0.64	Injection Molding
Polypropylene	15.00	2.03	Structural Foam Molding
Polystyrene	3.81	0.89	Injection Molding
Polystyrene	15.00	2.03	Structural Foam Molding
Polyurethane	50.80	1.52	Reaction Injection Molding

If the thickness of some portion of a part’s wall falls outside of this range, a corresponding Material Issue is listed under Plastic Issues.

In addition, the Thickness panel of the Design to Cost tab displays the Recommended Maximum and/or Recommended Minimum thickness.



Draft Issues: Draft Angle Thresholds

The lookup table `tblDraftAngle` specifies the minimum recommended draft angle for each material and process.

Material Type	Min Draft Angle (deg)	Process Name
ABS	0.25	Injection Molding
ABS	0.50	Structural Foam Molding
Acetal	0.25	Injection Molding
Acetal	0.50	Structural Foam Molding
Nylon	0.00	Injection Molding
Nylon	0.00	Reaction Injection Molding
Nylon	0.00	Structural Foam Molding
PET	0.25	Injection Molding
PET	0.50	Structural Foam Molding
Polycarbonate	0.25	Injection Molding
Polycarbonate	0.50	Structural Foam Molding
Polypropylene	0.25	Injection Molding
Polypropylene	0.50	Structural Foam Molding
Polystyrene	0.25	Injection Molding
Polystyrene	0.50	Structural Foam Molding
Polyurethane	0.25	Reaction Injection Molding

If the draft angle of some feature is less than the relevant minimum, a corresponding Draft Issue is listed under Plastic Issues.

Radius Issues: Minimum Internal and External Edge Radius

The lookup table `tblMinEdgeRadius` specifies the minimum recommended edge radius for each material and process.

Material Type	Min External Radii (mm)	Min Internal Radii (mm)	Process Name
ABS	0.38100	0.12700	Injection Molding
ABS	1.52400	1.52400	Structural Foam Molding
Acetal	0.38100	0.12700	Injection Molding
Acetal	1.52400	1.52400	Structural Foam Molding
Nylon	0.38100	0.12700	Injection Molding
Nylon	0.76200	1.58750	Reaction Injection Molding
Nylon	1.52400	1.52400	Structural Foam Molding
PET	0.38100	0.12700	Injection Molding
PET	1.52400	1.52400	Structural Foam Molding
Polycarbonate	0.38100	0.12700	Injection Molding
Polycarbonate	1.52400	1.52400	Structural Foam Molding
Polypropylene	0.38100	0.12700	Injection Molding
Polypropylene	1.52400	1.52400	Structural Foam Molding
Polystyrene	0.38100	0.12700	Injection Molding
Polystyrene	1.52400	1.52400	Structural Foam Molding
Polyurethane	0.76200	1.58750	Reaction Injection Molding

The same thresholds are used for sharp edges on the parting line.

Proximity Issues: Hole Proximity Issues

The distance between a hole and another feature must be greater than both the following:

- Diameter of the hole
- Twice the part average thickness

This cannot be configured without modification of a CSL module. Radius Issues: Minimum Internal and External Edge Radius

Hole Issues: Length-to-diameter (L/D) Ratio

The following cost model variables specify the L/D ratio thresholds for various types of holes:

- Small, blind holes: **smallBlindHoleDepthToDiaRatio** (2 in starting point VPEs)
- Large, blind holes: **largeBlindHoleDepthToDiaRatio** (3 in starting point VPEs)
- Small, through holes: **smallThroughHoleDepthToDiaRatio** (4 in starting point VPEs)
- Large, through holes: **largeThroughHoleDepthToDiaRatio** (6 in starting point VPEs)

The property **isBlind** is **true** for blind holes and **false** for through holes.

A hole is considered small if its diameter is less than the cost model variable **smallHoleDiamBorder** (4.7625mm in starting point VPEs). It is considered large otherwise.

18 Powder Metal Process Group

This chapter describes the costing details and inputs that are available for the Powder Metal process group.

This chapter includes the following topics:

- Powder metal overview
 - Powder metal processes
 - Powder metal material
 - Powder metal machines
 - Powder metal process routings
 - Powder metal process setup options
 - Powder metal costing details
-

Powder metal overview

Powder metal is typically used on small- to medium- sized parts at medium to high production volumes where wear resistance and corrosion resistance are critical. Typical parts made from powder metal include gears, bearings, cylinders, bushings, triggers, hammers, and other structural parts. The primary advantages to powder metal are the ability to create near to full net shape parts as well as maintain very close dimensional tolerances at high production volumes. aPriori's baseline cost model supports costing powder metal parts that are up to 8 inches in height and 25 pounds.

The powder metal process group enables estimation of manufacturing times and costs for compaction and sintering processes. The process model includes estimates for the tooling costs for the press used for compaction and the fixturing costs in sintering, if the user selects the use of flatness plates (by default in the aPriori starting point VPEs, flatness plates are not enabled).

Powder metal processes

The powder metal subprocesses available in aPriori include cold compaction pressing and atmospheric sintering.

Other compaction processes include hot compaction and warm compaction, which are not in the baseline powder metal process group, but could be deployed in a configured, customer-specific VPE.

Other sintering processes include vacuum sintering, which is not in the baseline powder metal process group, but could be deployed in a configured, customer-specific VPE.

Powder metal material

The powder metal process begins with a premixed powder of the required alloying elements as well as a lubricant. The aPriori baseline powder metal model assumes the powders are premixed. The baseline material costs include both the raw material and mixing costing.

Note If you want to cost the mixing process as a separate step in the routing, this option can be configured into a customer-specific VPE.

Powder metal is unique compared to other manufacturing processes because it supports the ability to design a material to fit very specific material property requirements. This in turn has allowed for a very significant amount of different metal alloys to be created. A list of publicly known materials used in the powder metal process is maintained by the Metal Powder Industry Federation (MPIF) in their publication of the Standard 35. This document is rich with material data and can be obtained through the MPIF.

Note Standard 35 does not list the required compaction curve information necessary for the model, so it must be calculated when adding materials to a VPE.

The aPriori baseline Powder Metal cost model has the following material properties in the material table:

- Material Name
- Material Description – Free form description of the material.
- Material Type – Material type drives the cut code. aPriori Support can point you to cut codes by material type and this information is available on the web.
- Cut Code – The cut code is used by the cycle time calculation in secondary machining processes.
- Unit Cost (\$/kg) – The cost per kilogram paid for the raw material.
- Green Density (kg/m³) – The green density of the part is the density of a part when it is pressed. At that time, the part is in its “green” state. No metallurgical bonds have been formed and the part holds its shape only as a result of the compaction. The parts can be easily cracked or broken by hand at this stage. In the powder metal process, this green density is typically in the range of 6.9g/cm³ for ferrous metals, however that is not a constant. The user will have the ability to change the green density of the part through a process setup option. Picking different green densities will result in a change in the required compaction pressure needed to compress the part to that specific density. The relationship between the green density and the compaction pressure will follow the compaction curve typically in the shape of a parabola. The resulting polynomial expression for the compaction curve is ultimately what drives the machine selection and the material cost per part.
- Apparent Density (kg/m³) – The apparent density of the material is the density of the raw material prior to compaction.
- Coef A – CoefA, Coef B, and Coef C are the coefficients of the compaction curve, which are used to determine the force required to press the powder to the required density. aPriori has a methodology for calculating the coefficients, which you can get from support, if you are looking to add materials into your specific VPE.
- Coef B – for the compaction curve, see explanation under CoefA.
- Coef C – for the compaction curve, see explanation under CoefA.

Powder metal material utilization

Material utilization options include:

- Computed – uses the default utilization, which is set as a process variable.
- Machine Default – average utilization for the selected machine is used, which is listed in the machine table.
- Override – user can enter a utilization rate.

Material cost = (part finished mass /utilization) * cost per Kg

Powder metal machines

The aPriori baseline machine selection logic for the press uses the green density of the specified material and compaction coefficients to determine the required compaction pressure. Next, the compaction pressure is multiplied by the projected cross sectional

area of the part to give a required force. The force is used to determine the required press.

You can manually select a different machine using the Edit Machine Selection window which lists the properties of all machines available at the facility. For information on how to select a different machine, see the "Selecting a machine for an operation" section of the aPriori *User Guide*.

The aPriori baseline powder metal model includes a set of hydraulic and mechanical (rigid frame) machines for the compaction pressing process, ranging from 12 to 1,600 tons. Hydraulic machines have multiple die sets (which can minimize the need for tool changes), can run at variable speeds during a cycle and are CNC programmable. Conversely, mechanical machines run at a constant speed during each cycle but may have die sets.

The aPriori baseline selects the sinter oven by assessing the size of the part and the belt speed, furnace length and belt width of the furnace. By default, aPriori selects the machine which results in the lowest sintering cost.

Powder metal process routings

A powder metal part will have a compaction pressing and furnace sintering process step in the routing. Alternatively, powder metal parts can also have secondary operations including forging, machining, heat treatment, surface treatment and /or packaging.

Powder metal process setup options

At the top-level, Powder Metal node, the following set-up options are available.

- Green Density. Default option is to use the green density provided in the material table, and the user has the ability to override. Please see the definition of Green Density and the impact of overriding this value in the Powder metal materials section above.

For Compaction pressing, the following set-up options are available:

- Compaction pressing process set-up options that impact piece part cost:

Compaction Press Stroke Rate. Default option is to use the calculated rate, and the user has the ability to override by specifying the number of cycles / minute.

Number of Press Operators. Default option is to use the value specified for the selected machine and the user has the ability to override by specifying the number of operators.

Material Allowance. Default is to use the calculated value, and the user has the ability to override by specifying the material allowance in millimeters.

- Compaction pressing process set-up options that impact tooling cost:

Backing Plate Thickness. Default is to use the calculated value, and the user has the ability to override by specifying the Backing Plate thickness in millimeters.

Select Punch Material. The aPriori baseline default is CPM-M4, and the user has the ability to select other materials.

Height of Upper Punch Member. Default is to use the calculated value, and the user has the ability to override by specifying the Height of the Upper Punch Member in millimeters.

Number of Lower Punches. The aPriori Baseline Default is 1 Lower Punch. The User can override and specify the number of Punches.

Height of First Lower Punch Member. The default is to use the calculated value and the user can override and specify the height in millimeters.

Height of Second Lower Punch Member. The default is to use the calculated value and the user can override and specify the height in millimeters.

Select Core Rod Material. The aPriori baseline default material is “CPM-10V” and the user can override by selecting a different material from the available list. List materials include: M2, CPM-M4, and CPM-10V.

Number of Core Rod Members. The aPriori baseline default calculates the number of required Core Rod Members and the user can override and specify the number of core members.

Length of the Core Rod Members. The default is to use the calculated value and the user can override and specify the height in millimeters.

For sintering, the following set-up options are available.

Sintering process set-up options that impact piece part cost:

- Number of Furnace Operators. Default option is to use the value specified for the selected machine (furnace) and the user has the ability to override by specifying the number of operators.

Sintering process set-up options that impact fixture cost:

- Enable Flatness Plates. By default, the Flatness Plates, which are used as a type of fixture to maintain flatness tolerances of the part, are not enabled and the user has the ability to enable them.

Powder metal costing details

The Powder Metal process group uses the following feasibility rules:

- Part size

Check part length and width against machine maximum dimensions.

Check fill height against maximum machine fill height

- Part shape

Check for fillets along edges against die perpendicular to the draw direction.

Check against minimum thicknesses

- Cycle time

Compaction time is driven by the stroke time of the presses. Stroke time considers the time for the shoe to move into place, fill the cavity, press the part, then lift it out of the cavity. This is one stroke. Stroke time is driven by the compaction force required to make a part and the size of the part.

Sintering time dependent on the size and weight of the parts. It is also dependent on the length of the furnace and the belt speed.

- Labor time cost drivers

Machine set up

Handling time, including part removal from press, part movement to sintering furnace, and final stacking

Processing time per machine is driven by machine cycle time and the number of operators manning the machine

- Tooling cost drivers

The major cost of tooling is the cost of machining the tool steels to form the dies.

Part length, width, number of faces, and surface finish drive cost of dies.

Complexity of top and bottom faces of the part drive the cost of the punches.

Multi step parts, or parts with multiple direction of pressing thicknesses may require multi stage punches used to aid in uniform density throughout the part.

The cost of core rods for a simple hole is driven by the size of the hole and the length of the rod required for a particular machine.

Complex core rods costs are driven by the number of faces in addition to those of simple core rods.

19 Rotational and Blow Molding Process Group

This chapter describes the costing details and inputs that are available for the Rotational and Blow Molding process group.

This chapter includes the following topics:

- Rotational and blow molding overview
 - Rotational and blow molding processes
 - Rotational and blow molding material
 - Rotational and blow molding machines
 - Rotational molding process setup
 - Blow molding process setup
 - Rotational and blow molding costing details
-

Rotational and blow molding overview

The Rotational and Blow Molding process group enables estimation of manufacturing times and costs for both rotational and blow molded plastic parts. The process models include estimates for the costs of manufacturing the mold.

Rotational and blow molding processes

The Rotational and Blow Molding process group includes a Rotational Molding and a Blow Molding routing. The Rotational Molding routing contains an optional Grind process (for grinding plastic pellets into powder), the Rotational Mold process (including coring and manual trimming operations), and a Router process. The Blow Molding routing contains the Extrusion Blow Mold process, a Saw process, and a Router process. Both routings also include subsequent optional surface treatment and packaging processes, if your company has licensed these modules.

Note Only the Blow Molding process is automatically evaluated (costed). To estimate the cost of a roto-molded part, open the Routing Editor and select the Roto Molding routing. For more information on selecting specific routings, see the "Selecting a process routing" section of the aPriori *User Guide*.

Rotational and blow molding material

The Rotational and Blow Molding process group allows you to view and edit values for composition and utilization. For more information on selecting a material composition and changing utilization, see the "Selecting a process routing" section of the aPriori *User Guide*.

Rotational and blow molding material composition

Material composition details include:

- Material Name
- Description
- Material Type
- Unit Cost (\$/kg)
- Density (kg/m³)
- Eject Deflection Temp (C)
- Melting Temp (C)
- Mold Temp (C)
- Thermal Diffusivity (mm²/sec)
- Can Blow Mold (true or false)

Rotational and blow molding material utilization

Material utilization details selections include:

- Computed — aPriori calculates material utilization by combining mold efficiency with regrind allowance.
- Machine Default — aPriori calculates material cost by dividing part finished mass by mold efficiency.
- Override — aPriori calculates material cost by dividing part finished mass by a user entered utilization rate.

Rotational and blow molding machines

By default, aPriori selects the default machine for each process in a given VPE. You can manually select a different machine using the Edit Machine Selection window which lists the properties of all machines available at the facility. For information on how to select a different machine, see the "Selecting a machine for an operation" section of the aPriori *User Guide*.

Rotational molding process setup

For rotational molded parts, aPriori allows you to define values and options for the following:

- Parting line/Draw direction
- Number of drop boxes
- Number of labels applied to one part
- Cost per label applied to the part
- Expected part shrinkage percentage
- Mold length margin
- Mold width margin
- Mold height margin
- Mold spacing margin
- Total number of molds used
- Colorant
- Enable part mirroring

Number of drop boxes

- Drop boxes may be used to introduce additional/distinctly colored layers of material in a part. The number of drop boxes may be specified in the following ways:
- Default Value = 0
- Override Value – you specify number of Drop Boxes ($> = 1$)

Number of labels applied to one part

- Labels may be applied following the Rotational Molding process:
- Default Value = 0
- Override Value – you specify number of Drop Boxes (> = 1)

Cost per label applied to the part

- Cost per label may be specified in the following manner:
- Default Value = \$1.00
- Override Value – you specify number of Drop Boxes (> 0.00)

Expected part shrinkage percentage

- Expected part shrinkage may be used to determine mold size from finished part. Expected part shrinkage may be specified in the following manner:
- Default Value
- Override Value – you specify Shrinkage Percent (0.00-99.99)

Mold length margin

- Mold Length Margin may be specified in the following manner:
- Default Value
- Override Value – you specify Mold Length Margin (> 0.00 mm)

Mold width margin

- Mold Width Margin may be specified in the following manner:
- Default Value
- Override Value – you specify Mold Width Margin (> 0.00 mm)

Mold height margin

- Mold Height Margin may be specified in the following manner:
- Default Value
- Override Value – you specify Mold Height Margin (> 0.00 mm)

Mold spacing margin

- Mold spacing margin refers to the spacing between adjacent molds on the rotational mold mounting plate. Mold Spacing Margin may be specified in the following manner:
- Default Value
- Override Value – you specify Mold Spacing Margin (> 0.00 mm)

Total number of molds used

- Total Number of Molds may be specified in the following manner:
- Default Value = 1
- Override Value – you specify Total Number of Molds ($> = 1$)

Colorant

Colorant may be specified in the following manners:

- No colorant added to raw material (default)
- Add colorant at standard rate: [0.75 \$/kg] – aPriori adds 0.75 \$/kg of material used
- User defined color charge – you specify cost per kg of material used

Enable part mirroring

Two parts per cavity may be specified by checking **Enable Part Mirroring**.

Blow molding process setup

For blow molded parts, aPriori allows you to define values and options for the following:

- Number of machine operators
- Number of labels applied to one part
- Cost per label applied to the part
- Colorant
- Maximum wall thickness
- Mold temperature

Number of machine operators

Number of Machine Operators may be specific in the following manner:

- Default Value = 0. The machine for this process is typically unmanned. Once set up and running, there is typically no manual intervention until the parts are being filled. The cost model accounts separately for labor involved in any follow on operations (for example, to create a hole in the part).
- Override Value – you specify Number of Machine Operators ($> = 1$)

Number of labels applied to one part

Labels may be applied during the blow molding process (in cycle):

- Default value = 0
- Override value – you specify number of drop boxes ($>=1$)

Cost per label applied to the part

Cost per label may be specified in the following manner:

- Default value = \$1.00
- Override value – you specify cost per label (> \$0.00)

Maximum wall thickness

- Maximum Wall Thickness may be derived from part file or overridden.
- Derive from Par File (default)
- Override Max Wall Thickness – you specify Max Wall Thickness (> 0.00 mm)

Mold temperature

- Default Mold Temperature may be overridden. Temperature specified must not exceed material Eject Deflection Temperature.
- Default Value = 27.00 °C
- Override Value – you specify Mold Temperature (> = 0.00 °C)

Rotational and blow molding costing details

The Rotational Molding process model uses the following costing rules:

- The complete rotational molding process is modeled as 3 stations: Load/Unload, Oven, and Cooling.
- Load and Unload cycle time computations account for core and insert installation and removal, mold clamping and unclamping, part removal, trimming, and mold cleaning time. Key geometric cost drivers include part surface area and mass, parting line perimeter length, and the perimeter length of holes that are trimmed or routed.
- Ideally, Oven Time is the rate-limiting portion of the entire 3-station cycle. If Load/Unload cycle times are computed to be greater than Oven Time, users can use the process setup options to increase the number of machine operators to lower the load/unload cycle time.
- Molds are assumed to be cast/machined aluminum (as opposed to cast/machined steel, or fabricated sheet metal). Tooling costs are driven primarily by part size and number of cores and inserts.
- By default, the rotational molding machine is assumed to be a 3-arm fixed carousel type machine. Other machine types are available for selection.

The Blow Molding process uses the following costing rules:

- A machine is considered acceptable if the following are true:

Part size is within limits of a machine compatible mold.

Machine clamp force is greater than or equal to required force.

- Number of cavities is optimized once a machine is selected.
- The cycle time model employs a “Maximum Wall Thickness” algorithm to calculate cooling time.
- Part must have at least one “spout” GCD.



20 Sheet Plastic Process Group

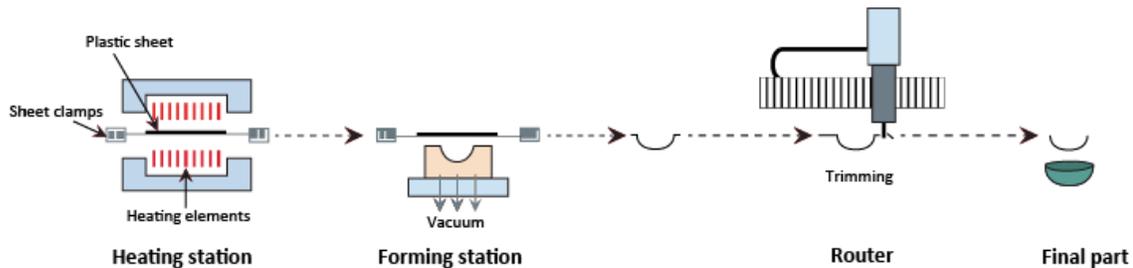
This chapter describes how aPriori models the costs associated with manufacturing heavy gauge, thermoformed sheet plastic components. The details of aPriori's Sheet Plastic cost model are organized within the Sheet Plastic process group and include alternative routings, processes, materials, machines, and general costing rules.

This chapter includes the following topics:

- Sheet plastic overview
 - Sheet plastic routings
 - Sheet plastic processes
 - Sheet plastic material
 - Sheet plastic machines
 - Sheet plastic costing details
-

Sheet plastic overview

The Sheet Plastic process group models the costs associated with manufacturing thermoformed sheet plastic components, including alternative routings, processes, materials, and machines, as well as the tooling costs associated with manufacturing the mold and any additional tooling pieces, such as plugs or pressure boxes. The following figure illustrates a simple thermoforming process.



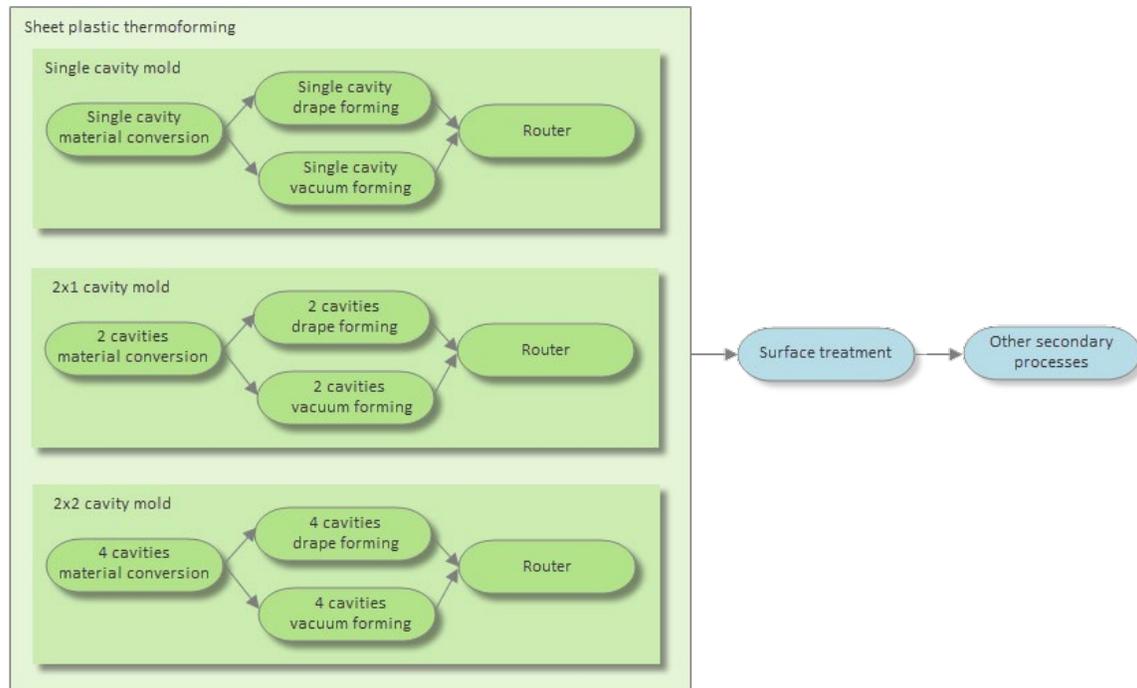
A sheet plastic component begins life as plastic pellets. The pellets are first converted into an extruded sheet and cut to size. The simple process illustrated above shows a cut sheet progressing through heating, forming (including cooling) and finally trimming. These steps represent the basic steps supported in aPriori, with pre-stretching, pressure, and numerous additional process setup options available to refine your thermoforming cost estimate.

Heavy gauge thermoforming is used to make a variety of parts, including automobile door liners and instrument panels, and even small pools and spas. Thin-gauge thermoforming is widely known as the optimal process for manufacturing containers, including blister packaging and disposable cups. aPriori's Sheet Plastic process group focuses on generating cost estimates for heavy gauge parts primarily found in industrial and OEM products.

The Sheet Plastic process group is a separately licensed module. Please contact your aPriori Account Executive or aPriori Support if you require these features in your aPriori solution.

Sheet plastic routings

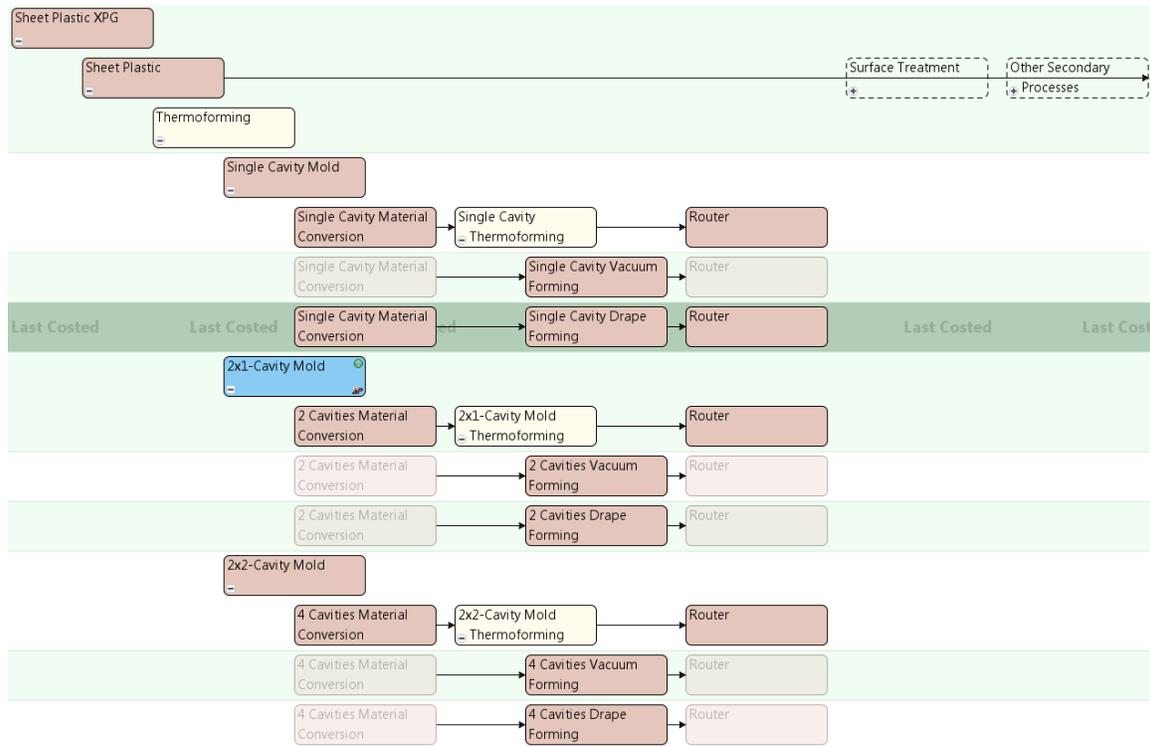
aPriori's sheet plastic cost model has six alternative routings. Each routing includes subsequent optional surface treatment and packaging processes, if your company has licensed these modules. The following figure illustrates how aPriori models all the potential ways that thermoformed sheet plastic components can be manufactured.



The sheet plastic routings are organized within three branches, based on the number of cavities in the mold. Within each of these branches, aPiori includes a material conversion process, two alternative thermoforming processes (a drape forming process for a positive mold and a vacuum forming process for a negative mold), and a router process.

To display routing information

Select **Edit > Routing Selection** to display the alternative routings in the **Routing Selection** window.



Sheet plastic processes

For each mold type, aPuri uses a **Material Conversion** process to model the costs of sheet extrusion for the sheet size and run appropriate to the mold and production volume; a **Drape** or **Vacuum Thermoforming** process to model creating the component; and a **Router** process to model costs of secondary features, such as holes or slots, and to model trimming costs.

Material conversion processes

aPuri includes a sheet plastic conversion process to model sheet extrusion cost in every sheet plastic routing because sheet dimensions and costs vary too dramatically to be represented by even an extensive stock list. Each routing begins with a **Material Conversion** process specific to the number of cavities. The conversion process models the cost of converting the pellets to a sheet, and accounts for the cost savings from trimmed material that is sold back to the sheet supplier.

To select the material conversion machine

- Do one of the following to display the **Machine Selection** window:
 - If the material conversion node (**Single Cavity Material Conversion**, **2 Cavities Material Conversion**, or **4 Cavities Material Conversion**) is included in the current routing, right-click the node in the **Manufacturing Process** pane and select **Machine Selection** from the context menu.
 - If the node is not included in the current routing, select **Edit > Routing Selection** in the **Manufacturing Process** pane to display the **Routing Selection**

window, then right-click the node and select **Machine Selection** from the context menu.

- 2 Select one of the following options:
 - **aP Select** – aPriori automatically selects the lower cost sheet extrusion machine based on the dimensions of the starting sheet.
 - **User Select** – Manually select the machine from a list.
- 3 Click **OK** to save your changes and close the window.

To configure the material conversion process

- 1 Do one of the following to display the **Process Setup Options** window:
 - If the **Thermoforming** branch node is included in the current routing, right-click the node in the **Manufacturing Process** pane and select **Process Setup Options** from the context menu.
 - If the node is not included in the current routing, select **Edit > Routing Selection** in the **Manufacturing Process** pane to display the **Routing Selection** window, then right-click the node and select **Process Setup Options** from the context menu.
- 2 Modify any of the following options:
 - **Starting Gauge Determination** – aPriori uses the wall thickness of the component from the CAD file to determine the initial thickness of the plastic sheet before forming (which stretches the plastic, reducing its thickness). You can select **Desired Ending Wall Thickness is Equivalent to CAD Model** to use the average wall thickness of the CAD model to calculate the starting gauge instead.
 - **Starting Gauge** – aPriori automatically calculates the required starting gauge based on the selected starting gauge determination, clamp width, the component's geometry, and overall draw ratio. You can select **Override Starting Gauge** and enter a value in the field to specify the starting gauge manually.
- 3 Click **OK** to save your changes and close the window.
- 4 Click **OK** on the **Routing Selection** window to close the window and re-cost the component using the modified processes.

You can click **Apply** to re-cost the component without closing the window.

Thermoforming processes

aPriori models costs of thermoforming by drape forming or vacuum forming, based on the number of cavities.

- **Single, 2x1, and 2x2 Cavity Drape Forming** – In this process, the heated sheet is formed over a positive mold.
- **Single, 2x1, and 2x2 Cavity Vacuum Forming** – In this process, the heated sheet is formed in a negative mold.

These processes are for heavy-gauge thermoforming, with an initial sheet thickness of 2mm (0.120 inches) to 13mm (0.500 inches).

You can configure the drape forming and vacuum forming processes to include pre-stretching and pressure assist. Pressure assist is only supported for vacuum forming, but plug-assisted pre-stretching is supported for both thermoforming processes.

To configure the common thermoforming process

- Do one of the following to display the **Process Setup Options** window:
 - If a mold branch node (**Single Cavity Mold**, **2x1 Cavity Mold**, or **2x2 Cavity Mold**) is included in the current routing, right-click the node in the **Manufacturing Process** pane and select **Process Setup Options** from the context menu.
 - If the node is not included in the current routing, select **Edit > Routing Selection** in the **Manufacturing Process** pane to display the **Routing Selection** window, then right-click the node and select **Process Setup Options** from the context menu.
- Modify any of the following component cost driver options:

Option	Description
Two cavities mold orientation	For the 2x1 Cavity Mold process, aPriori assumes the two cavities are oriented along the part length direction, but you can select Along the Part Width Direction from the drop-down list to model the costs associated with that mold orientation. This option is available only for the 2x1 Cavity Mold process.
Initial sheet sizes	aPriori automatically calculates the dimensions of the sheet required to create the component.
Initial sheet length	aPriori automatically calculates the initial sheet length based on the component's geometry and the stretch factor of the selected material, but you can select Override Initial Sheet Length and enter a value to specify the length manually.
Initial sheet width	aPriori automatically calculates the initial sheet width based on the component's geometry and the stretch factor of the selected material, but you can select Override Initial Sheet Width and enter a value to specify the width manually.
Colorant cost	aPriori uses a colorant cost based on gray by default. You can select another colorant cost from the Colorant Cost drop-down list or select Override Colorant Cost and enter the exact cost of the colorant pellet in the field.
Let down ratio (LDR)	aPriori uses a default let-down ratio to model the percentage of colorant pellets to plastic pellets by mass. For example, a let-down ratio of 0.04 means that there are four kilograms of colorant pellets and 96 kilograms of plastic pellets in 100 kilograms of material. You can select Override Colorant Let Down Ratio and enter a value in the field to specify the percentage of colorant pellets manually.

3 Modify any of the following tooling cost driver options:

Option	Description
Number of undercuts	An undercut is required when a part has a “T” shape, where the top of the mold must collapse so that the part can be drawn out of the bottom of the mold. aPriori automatically calculates the number of undercuts based on the component’s geometry, but you can select Override Number Of Undercuts and enter a value in the field to specify the number manually.
Undercut handling	This option lets you specify whether a mold contains a removable (core) or actuated insert. Actuated inserts expand and contract to allow the part to be removed from the mold. aPriori assumes that removable inserts are used, but you can select Actuated Inserts from the drop-down list to include the costs associated with this type of mold insert.
Mold frame standard	aPriori assumes that the molds used for sheet plastic have the basic mold frame, but you can select High Quality Mold Frame from the drop-down list if you want to model the costs associated with higher quality molds.

4 Click **OK** to save your changes and close the window.

5 Click **OK** on the **Routing Selection** window to close the window and re-cost the component using the modified processes.

You can click **Apply** to re-cost the component without closing the window

To configure the drape forming and vacuum forming processes

1 Do one of the following to display the **Process Setup Options** window:

- If a thermoforming process is included in the current routing, right-click the node in the **Manufacturing Process** pane and select **Process Setup Options** from the context menu.
- If the process is not included in the current routing, select **Edit > Routing Selection** in the **Manufacturing Process** pane to display the **Routing Selection** window, then right-click the node and select **Process Setup Options** from the context menu.

2 Modify any of the following options:

- **Cooling time** – aPriori automatically calculates the time required to cool the plastic sheet before it can be removed from the mold based on sheet thickness and material type, but you can select **Override Cooling Time** and enter a value in the field to specify the cooling time manually.
- **Pressure forming required** – aPriori automatically calculates the additional costs associated with pressure-assisted forming, including tooling and machine cost increases as well as the change in forming time. This option is available only for vacuum forming.

- **Pre-stretching required** – aPiori automatically calculates the cost of pre-stretching the heated sheet using temperature-controlled cast aluminum plugs and adjusts the forming time.
- 3 Click **OK** to save your changes and close the window.
 - 4 Click **OK** on the **Routing Selection** window to close the window and re-cost the component using the modified processes.
You can click **Apply** to re-cost the component without closing the window.

Router process

The **Router** process is used to trim the finished component and add any secondary features, such as holes or slots.

Sheet plastic material

You can display and edit the costs associated with the materials used to make sheet plastic components. For more information, see the "Selecting material" section of the *aPiori User Guide*.

You can override the sheet plastic material unit cost by entering a converted material cost to prevent aPiori from modeling the conversion cost applied to the listed material unit costs. aPiori still applies a buyback cost for any trim to calculate total material cost. This material cost override behavior is unique to the Sheet Plastic process group. For more information, see *Sheet plastic material unit cost* on page 1152.

To display sheet plastic material information

- 1 Check that **Sheet Plastic** is selected as the **Primary Process Group** on the **Manufacturing Process** pane.
- 2 Select **Edit > Material Selection** on the **Manufacturing Process** pane to display the costs associated with sheet plastic materials on the **Material Selection** window.

Sheet plastic material unit cost

You can specify how aPiori should calculate the unit cost of the material. You may want to specify this cost if you purchase sheets from a supplier and you know how much you pay for those sheets.

Select:

- **VPE Material Unit Cost** to use the cost of the raw pellets specified in the VPE.
- **Override** and enter the cost of the sheets from your supplier in the field to specify the cost by mass of the plastic sheet (that is, the cost after the pellets have been converted to a sheet).

If you override the material unit cost, the **Conversion** process still appears in the routing because in addition to modeling the cost of converting the pellets to a sheet, it accounts for the cost savings from trimmed material that can be sold back to the sheet supplier.

Sheet plastic material composition

The following material composition properties affect the cost of the sheet plastic component:

- **Name** – Reference field containing the specific name of the material.
- **Description** – Reference field containing material descriptors.
- **Material Type** – Reference field containing the generic name of the material type.
- **Unit Cost** – Cost per mass of the unconverted raw plastic pellets.
- **Max Draw Ratio** – aPiori calculates the overall draw ratio based on the component's geometry. The calculated draw ratio must not exceed the maximum draw ratio for the material shown in this field.
- **Normal Forming Temp** – The temperature at which the sheet is normally formed. A higher normal forming temperature requires additional time for heating and cooling the sheet, resulting in a higher cycle time and associated cost.
- **Upper Forming Temp** – A temperature at the upper end of the range at which the material can be formed.
- **Lower Forming Temp** – A temperature at the lower end of the range at which the material can be formed.
- **Set Temp** – The temperature at which the sheet is considered structurally stable for release from the mold. A higher set temperature means the sheet becomes stable more quickly, resulting in a lower cooling cycle time and associated cost.
- **Density** – Material density. More dense materials result in a greater mass per sheet and affect cost based on the material's unit cost.
- **Morphology** – Reference field that affects average cooling thermal diffusivity. Crystalline material has a lower average thermal diffusivity than amorphous material, resulting in a higher cycle time and associated cost.
- **Average Thermal Diffusivity** – Measure of thermal inertia of a material. Material with a higher thermal diffusivity value conducts heat more quickly relative to its volumetric heat capacity, resulting in a lower cycle time and associated cost.

Sheet plastic material utilization

You can specify how aPiori should calculate material utilization. Select:

- **Computed** to calculate material utilization by calculating rough mass and finish mass with trim allowance
- **Machine Default** to calculate sheet cost by dividing part finished mass by standard process efficiency
- **Override** to calculate sheet cost by dividing part finished mass by a user-entered utilization rate

Sheet plastic machines

aPiori automatically selects the VPE's default machine for each process, but you can manually select a different machine. For information on how to select a different

machine, see the "Selecting a machine for an operation" section of the aPriori *User Guide*.

Sheet plastic costing details

The sheet plastic process model uses the following costing rules:

The default behavior is to select the lowest cost routing, which will optimize the number of cavities.

Starting sheet size is used to determine machine feasibility.

Pressure assist is supported for vacuum forming only.

Machine A is considered better than Machine B if the forming area of A is less than that of B.

Calculation of machine cycle time assumes the following:

- Load time is equal to unload time.
- Load and unload time includes clamp/unclamp and core installation times.
- Cooling time includes forming time.
- Heating time is equal to cooling time. (Heating time is actually typically less than cooling time, so this assumption serves to make the cycle time estimate more conservative.)

The number of machine stations affects how cycle time is calculated:

Machine Cycle Time = {
2 * (Load Time + Cooling Time), for Single Shuttle Machine
Load Time + Cooling Time, for Double Ender Machine
Max(Load Time, Cooling Time), for Three-Station Rotary}

Cooling time is calculated based on the assumption of quiescent ambient air, so this calculation is conservative for moving ambient air.

Machine cycle time is adjusted to account for any pressure assist and any pre-stretching.

21 Additive Manufacturing Process Group

This chapter describes the costing details and inputs that are available for the Additive Manufacturing (AM) process group. This process group enables estimation of manufacturing times and costs for four distinct types of AM, as well as subsequent surface treatment, heat treatment, inspection, and packaging processes if applicable.

This chapter includes the following topics:

- Process Routing for Additive Manufacturing
 - Materials for Additive Manufacturing
 - Process Feasibility for Additive Manufacturing
 - Machine Selection for Additive Manufacturing
 - Additive Manufacturing Formulas
 - User Inputs for Additive Manufacturing
-

Process Routing for Additive Manufacturing

The Additive Manufacturing routings available in aPriori include the following:

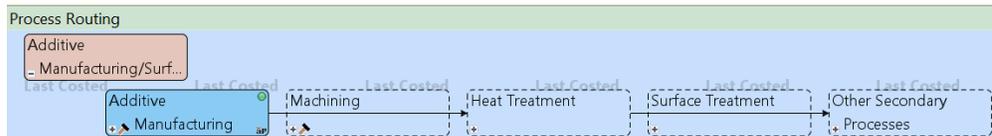
- Material Jetting Routing
- Selective Laser Sintering (SLS) Routing (under the **Powder Bed Fusion** routing node)
- Direct Metal Laser Sintering (DMLS) Routings (under the **Powder Bed Fusion** routing node)
- Stereolithography (SLA) Routing (under the **Vat Polymerization** routing node)

For all routings, Machining is included if the user specifies tolerances that are not achievable by the primary process.

In addition, DMLS routings require, by default, all the following:

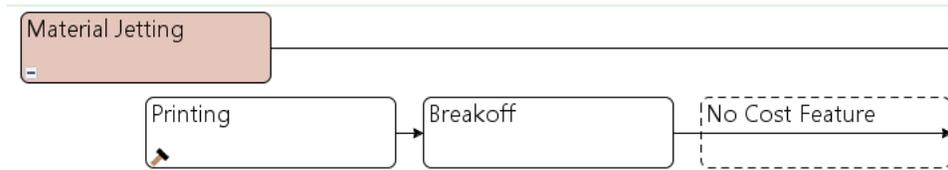
- Wire EDM from Machining
- 3-Axis Mill or 5-Axis Mill from Machining
- Ultrasonic Cleaning from the Other Secondary Processes group
- Stress Relief from the Heat Treatment process group

You can also manually include processes from Heat treatment, Surface Treatment, and Other Secondary Processes. And you can manually assign machining operations to individual GCDs.



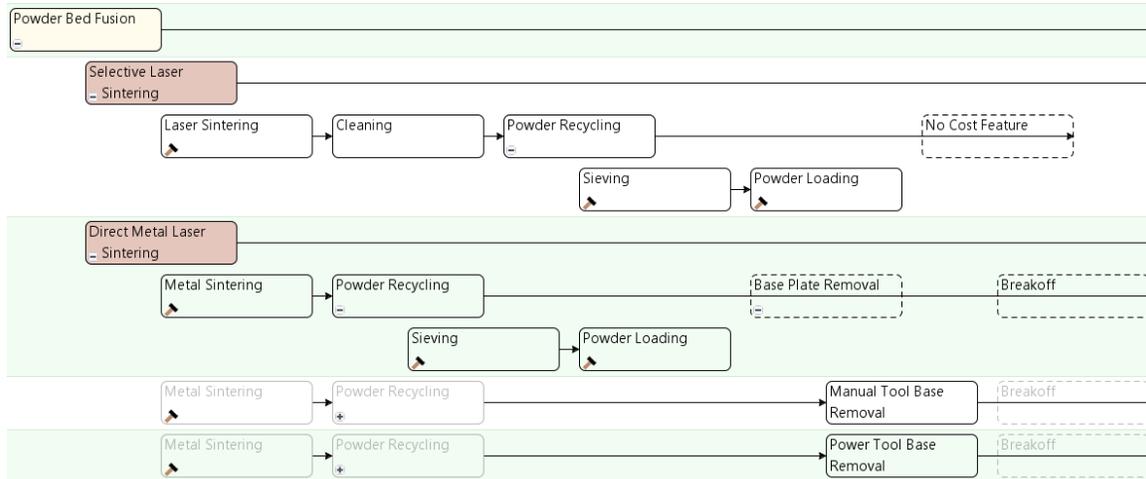
Material Jetting Routing

Material Jetting includes the following processes:



- Printing
- Breakoff (removal of support structures)

The Powder Bed Fusion routings are shown below:



Selective Laser Sintering (SLS) Routing

Selective Laser Sintering includes the following processes:

- Laser Sintering
- Cleaning
- Sieving
- Powder Loading

Direct Metal Laser Sintering (DMLS) Routings

Direct Metal Laser Sintering includes the following processes:

- Metal Sintering
- Sieving
- Powder Loading
- Manual Base Removal or Power Tool Base Removal (removal of base support structures; must be manually included if Wire EDM is manually excluded—see below)
- Breakoff (removal of support structures, except base support structures)

With metal sintering, parts are constructed on a *base plate*, a steel build platform positioned on the machine bed. The cost model assumes that the base plate is machined between runs.

By default, in order to model removal of the base plate from the base support structure, aPuri assigns to the Build Direction GCD the Base Plate Removal operation of the Wire EDM process (from the Machining process group). The Base Plate Removal operation is performed on the portion of the base plate that was occupied by the array of nested parts (that is, the smallest build-plate-aligned rectangle that encloses all the parts).

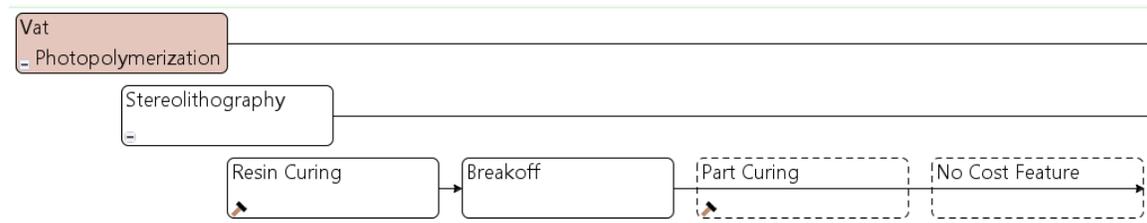
You can override the default, and instead model base plate removal with Manual Tool Base Removal or Power Tool Base Removal, by manually including one of these processes (under the Base Plate Removal node in the Additive Manufacturing process group). Manual Tool Base Removal and Power Tool Base Removal each have an operation (Base Removal Manual or Base Removal Power) that is performed on each Support Structure GCD.

In addition, in order to model base plate finishing subsequent to base plate removal, aPriori assigns Base Plate Facing (a child of 3-Axis Mill or 5-Axis Mill in the Machining process group) to the Build Direction GCD. Facing is performed on the entire surface area of the base plate (the product of machine **Bed Length** and **Bed Width**). Note that if wire EDM and facing are performed, facing appears first in the Manufacturing Process pane even though this doesn't match the actual operation order.

DMLS routings also include Stress Relief from the Heat Treatment process group, as well as Ultrasonic Cleaning from the Other Secondary Processes process group.

Stereolithography (SLA) Routing

Stereolithography includes the following processes:



- Resin Curing
- Breakoff (removal of support structures)
- Part Curing

Materials for Additive Manufacturing

Material properties include:

- **Material Name**
- **Process:** indicates whether the material is used for Printing, SLS, SLA, or DMLS.
- **Description**
- **Manufacturer**
- **Material Type**
- **Unit Cost** (cost per unit mass)
- **Density:** density of the material in the final part
- **Tapped Density** (DMLS and SLS only): tapped density of the material in the powder state, that is, the density of the metal powder in the build chamber just before it is sintered. This is typically about 62.3% of the density of material that has been made solid by sintering.

Note: Each type of material available in the aPriori starting point VPEs is compatible with only one of the four additive manufacturing routings, and may be compatible with only some of the machines for that routing. See [Machine Selection for Additive Manufacturing](#).

Process Feasibility for Additive Manufacturing

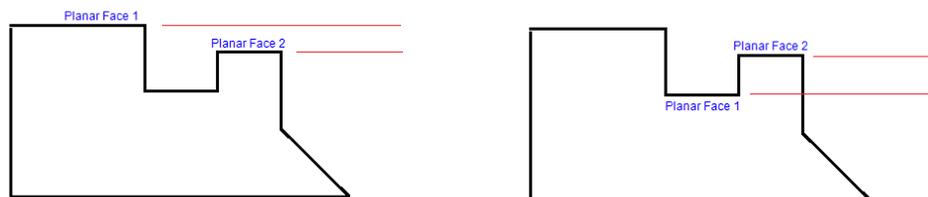
The main process of each routing (Printing, Laser Sintering, Metal Sintering, or Resin Curing) is subject to the following material constraint and minimum layer thickness constraint:

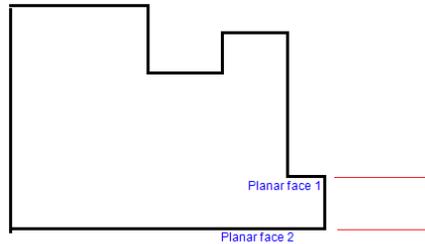
- Current material's **Process** property is set to the current process:
 - For Printing, the material's **Process** property is **3D Printing**.
 - For Laser Sintering, the material's **Process** property is **SLS**.
 - For Metal Sintering, the material's **Process** property is **DMLS**.
 - For Resin Curing, the material's **Process** property is **SLA**.
- If the setup option **Minimum Layer Thickness Check** is set to **true** (it is **false** by default), the part can be built with the minimum layer thickness for the current process, as given by the lookup table **tblLayerThickness**.

tblLayerThickness	
Minimum Layer Thickness (mm)	Process Name
0.02	Metal Sintering
0.03	Stereolithography
0.10	Laser Sintering
0.13	Printing

The cost model determines that the part cannot be built with a given layer thickness if the difference between the heights of some pair of surfaces is less than the given thickness. (aPriori determines the height of a given surface by considering the Is Accessible From relation between that surface and a setup axis that is co-directional with the build direction. The Tool Reach property of this relation gives an indication of the height; Tool Reach is smaller for higher surfaces.)

In the illustrations below, the pairs of parallel red lines indicate the difference between the heights of various pairs of planar faces.





Machine Selection for Additive Manufacturing

By default, for each AM process, aPiori selects the feasible machine with the lowest overhead rate, where overhead rate is the sum of the machine properties **Direct Overhead Rate** and **Indirect Overhead Rate**.

Machine feasibility constraints, for those processes that have them, are covered in the following sections:

- Machine Feasibility for Printing
- Machine Feasibility for Laser Sintering
- Machine Feasibility for Metal Sintering
- Machine Feasibility for Resin Curing
- Machine Feasibility for Part Curing

aPiori selects only from preferred machines, if there is a feasible preferred machine of the appropriate type and the cost model variable **usePreferredMachines** is set to **true** (the default in starting point VPEs). If there is no feasible preferred machine of the appropriate type, or if the cost model variable **usePreferredMachines** is set to **false**, aPiori selects from all machines. A machine is preferred if the machine property **isPreferred** (typically displayed as **Is Preferred**) is **true**.

You can manually select a machine using the Edit Machine Selection window, which lists the properties of all machines available at the facility.

Machine Feasibility for Printing

Feasible Printing machines satisfy all the following:

- Part length and width, and height are no greater than the machine properties **Bed Length** and **Bed Width**, respectively.
- Part height together with base material height is no greater than the machine property **Bed Height**. The base material is the buffer of unsintered material between the bottom layer of parts and the base plate. By default, the base height is specified by the site variable **basePlateOffset** (10mm in starting point VPEs). Users can override the default base height with the setup option **Base Plate: Support Structures Height**.
- The value of the material's **Manufacturer** property is the same as the value of the machine's **Manufacturer** property.

- Either the machine is a preferred machine, or there is an entry in the lookup table **tblMaterialCompatibility** that has the current machine name, material name, and process (3D Printing).

Note that the part's orientation (see [Using the Build Direction Tool to Orient the Part](#)) determines which dimension of the part's bounding box is the height. The length is the longer of the other two dimensions.

Machine Feasibility for Laser Sintering

Feasible Laser Sintering machines satisfy both the following:

- Part length and width, and height are no greater than the machine properties **Bed Length** and **Bed Width**, respectively.
- Part height together with base material height is no greater than the machine property **Bed Height**. The base material is the buffer of unsintered material between the bottom layer of parts and the base plate. By default, the base height is specified by the site variable **buildPlateOffset** (10mm in starting point VPEs). Users can override the default base height with the setup option [Base Powder Height](#).
- Either the machine is a preferred machine, or there is an entry in the lookup table **tblMaterialCompatibility** that has the current machine name, material name, and process (SLS).

Note that the part's orientation (see [Using the Build Direction Tool to Orient the Part](#)) determines which dimension of the part's bounding box is the height. The length is the longer of the other two dimensions.

Machine Feasibility for Metal Sintering

Feasible Metal Sintering machines satisfy both the following:

- Part length and width, and height are no greater than the machine properties **Bed Length** and **Bed Width**, respectively.
- Part height together with base-structure height is no greater than the machine property **Bed Height**. The base structure provides a buffer the parts and the base plate. By default, the base height depends on which base-structure-removal process is included in the current routing—see [Support Structures for Metal Sintering](#). Users can override the default base height with the setup option [Base Plate: Support Structures Height](#).
- Either the machine is a preferred machine, or there is an entry in the lookup table **tblMaterialCompatibility** that has the current machine name, material name, and process (DMLS).

Note that the part's orientation (see [Using the Build Direction Tool to Orient the Part](#)) determines which dimension of the part's bounding box is the height. The length is the longer of the other two dimensions.

Machine Feasibility for Resin Curing

Feasible machines for Resin Curing satisfy the following:

- Part length and width, and height are no greater than the machine properties **Bed Length** and **Bed Width**, respectively.
- Part height together with base material height is no greater than the machine property **Bed Height**. The base material is the buffer of unsintered material between the bottom layer of parts and the base plate. By default, the base height is specified by the site variable **basePlateOffset** (10mm in starting point VPEs). Users can override the default base height with the setup option **Base Plate: Support Structures Height**.
- Either the machine is a preferred machine, or there is an entry in the lookup table **tblMaterialCompatibility** that has the current machine name, material name, and process (SLA).

Note that the part's orientation (see [Using the Build Direction Tool to Orient the Part](#)) determines which dimension of the part's bounding box is the height. The length is the longer of the other two dimensions.

Machine Feasibility for Part Curing

Feasible machines for Part Curing satisfy the following:

- Part length, width, and height are no greater than the machine properties **Bed Length**, **Bed Width**, and **Bed Height**, respectively. Note that the part's orientation (see [Using the Build Direction Tool to Orient the Part](#)) determines which dimension of the part's bounding box is the height. The length is the longer of the other two dimensions.
- Part mass (part volume times material density) is no greater than the value of the machine property **Maximum Mass**.
- If the current material's **Material Type** property is **LaserForm**, the machine property **Can Cure LaserForm Materials** is **true**.

Additive Manufacturing Formulas

Formulas and calculations for AM are covered in the following sections:

- [Accounting Formulas for Additive Manufacturing](#)
- [Yield Formulas for Additive Manufacturing](#)
- [Printing Formulas](#)
- [Laser Sintering Formulas](#)
- [Metal Sintering Formulas](#)
- [Resin Curing Formulas](#)
- [Breakoff Formulas](#)
- [Manual Tool Base Removal Formulas](#)
- [Power Tool Base Removal Formulas](#)
- [Cleaning Formulas](#)
- [Part Curing Formulas](#)

- Sieving Formulas
- Powder Loading Formulas

Accounting Formulas for Additive Manufacturing

Labor time and cost is 0 for Printing, Laser Sintering, Resin Curing, and Part Curing. Labor time depends on powder removal time for Metal Sintering (see [Metal Sintering Formulas](#)). The other processes use the following Labor Cost formulas:

Labor Cost = Labor Time * Labor Rate / Final Yield

Labor cost is a function of the following:

- Labor time (see formula below)
- Labor rate (specified by the machine property **Labor Rate**)
- Final yield (see [Yield Formulas for Additive Manufacturing](#))

Labor Time = Cycle Time * Labor Time Standard * Number of Operators

Labor time is the product of the following:

- Cycle time (see the sections on the individual processes, below)
- Labor time standard: specified as the machine property **Labor Time Standard**. This multiplier is used to account for otherwise unaccounted for factors that affect labor time, such as operator fatigue or time spent by the operator for cleaning or maintenance.
- Number of operators (specified by the machine property **Number of Operators**)

Yield Formulas for Additive Manufacturing

These formulas apply to all Additive Manufacturing processes.

Final Yield = Final Output Volume / Local Input Volume

Final yield affects material, labor, and overhead costs per part. It is the fraction of parts created by this process in the current production scenario that will survive as good parts once any secondary processes are completed. That is, final yield is the fraction of parts created by this process that are *not* discarded as scrap parts, either by this process or by a downstream process. Final yield depends on the following:

- Final output volume is the number of parts created by this process that are *not* discarded as scrap parts, either by this process or by a downstream process. It is the product of the annual volume and number of production years, specified in the Production Scenario screen of the Cost Guide.
- Local Input volume (see the formula below). This is the total number of parts produced by this process, including all parts discarded as scrap from this process or downstream processes.

Local Input Volume = Local Output Volume + Number of Scrap Parts for This Process

Local input volume is the total number of parts produced by this process in the current scenario, including all parts discarded as scrap from this process or downstream processes. It is the sum of the following:

- Local output volume (see the formula below). This is the number of parts produced by this process, excluding parts discarded as scrap by this process, but including parts that are discarded as scrap by downstream processes.
- Number of scrap parts for this process (see the formula below)

Local Output Volume = Final Output Volume + Number of Scrap Parts Downstream

Local output volume is the number of parts produced by this process in the current scenario, excluding parts discarded as scrap by this process, but including parts that are discarded as scrap by downstream processes. It is the sum of the following:

- Final output volume is the number of parts created by this process that are *not* discarded as scrap parts, either by this process or by a downstream process. It is the product of the annual volume and number of production years, specified in the Production Scenario screen of the Cost Guide
- Number of Scrap Parts Downstream. This the number of parts discarded as scrap by downstream processes.

Number of Scrap Parts for This Process = (Local Output Volume / Local Good Part Yield) – Local Output Volume

Number of scrap parts for this process is the number of parts produced by this process in the current scenario that are discarded as scrap by this process, before any downstream process is performed on them. It is a function of the following:

- Local output volume (see the formula above). This is the number of parts produced by this process, excluding parts discarded as scrap by this process, but including parts that are discarded as scrap by downstream processes.
- Local good part yield (specified by the machine property **Good Part Yield**). This is the fraction of parts produced by this process that are not discarded as scrap by this process but may be discarded as scrap by downstream processes.

Printing Formulas

Formulas and calculations used by the Printing process are described in the following sections:

- [Setup Formula for Printing](#)
- [Cycle Time Formulas for Printing](#)
- [Number of Parts for Printing](#)
- [Material Cost Formulas for Printing](#)
- [Additional Direct Costs—Support Structures for Printing](#)

Setup Formula for Printing

Amortized Batch Setup = (Setup Time * (Labor Rate + Direct Overhead Rate)) / Batch Size

Batch setup cost per part depends on the following:

- Setup time: by default, this is specified by the cost model variable **loadFileAndSpliceTime** (0.25 hours in starting point VPEs). Users can override the default and specify the setup time with the setup option [Load and Splice Time](#).
- Labor rate (specified by the machine property **Labor Rate**)

- Direct overhead rate (see [Direct and Indirect Overhead](#))
- Batch size (specified in the **Production Scenario** screen of the Cost Guide)

Cycle Time Formulas for Printing

Cycle Time = Process Time * Adjustment Factor

Cycle time is the product of the following:

- Process time (see formula)
- Adjustment factor (specified by the cost model variable **cycleTimeAdjustmentFactor**). This factor is 1 in aPiori starting point VPEs. VPE administrators can modify **cycleTimeAdjustmentFactor** in order to adjust cycle times across processes within the current VPE.

Process Time = (Build Time + Preprocessing Time) / Number of Parts

Process time is the sum of the following:

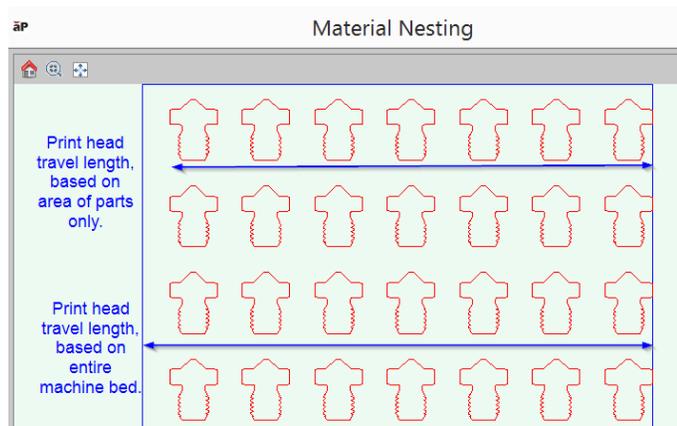
- Build time (see formula)
- Preprocessing time: by default, this is specified by the cost model variable **printingPreprocessingTime** (1200 seconds in starting point VPEs). Users can override the default on a part-by-part basis with the setup option [Preprocessing Time](#).
- Number of parts (see [Number of Parts for Printing](#), below)

Build Time = (Print Head Travel Length / Layer Speed) * Swipes * Layers + (Print Head Travel Width / Layer Speed) * Passes

Build time depends on the following:

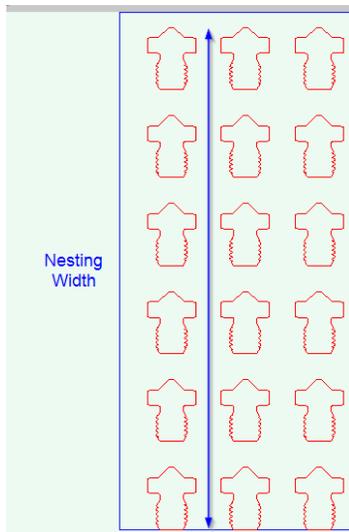
- Print head travel length: this is the distance the print head travels along the length dimension of the build chamber to create a single strip one layer thick.

By default, this length is the length of the array of nested parts (that is, the length of the smallest build-plate-aligned rectangle that encloses all the parts). With the setup option [Print Head Travel Type](#), users can override the default, and specify that the print head travel length is the length of the entire machine bed (specified by the machine property **Bed Length**).



- Layer speed: this is the rate at which the print head travels along the length dimension of the build chamber. The rate is specified by the machine property **Layer Speed**.

- **Swipes:** this is the number of swipes required to build a complete, horizontal cross-section of all parts one layer thick. See the formula below.
- **Layers:** this is the height of the part in layers, that is, the number layers in one complete, vertical cross section of the part and support base. See the formula below.
- **Print head travel width:** this is the nesting width (the width of the array of nested parts) minus the scanning width (specified by the machine property **Scanning Width**). (If the nesting width is less than the scanning width, print head travel width is 0.)



- **Passes:** this is the number of times the print head travels the nesting length or machine bed length before moving in the width direction. By default, the number is specified by the cost model variable **defaultNumPrintHeadPasses** (2 in starting point VPEs). Users can override the default with the setup option **Number of Print Head Passes**.

Swipes = Nesting Width / Scanning Width

The number of swipes required to build a layer-thick cross-section of the part depends on the following:

- **Nesting width:** this is the width of the array of nested parts (that is, the width of the smallest build-plate-aligned rectangle that encloses all the parts).
- **Scanning width** (specified by the machine property **Scanning Width**)

Layers = roundup((Part Height + Base Support Structure Height) / Adjusted Layer Thickness)

The height of the part in layers depends on the following:

- **Part height** (the height of the part's bounding box, specified by geometry extraction)
- **Base support structure height:** this is the height of the support structure that separates the part from the build platform (which protects the part from damage when the operator scrapes the finished part off of the platform). By default, the height is specified by the site variable **buildPlateOffset** (10mm in starting point

VPEs). Users can override the default with the setup option **Base Plate: Support Structures Height**.

- **Adjusted layer thickness:** by default, this is specified by the machine property **Layer Thickness**. Users can override the default on a part-by-part basis with the setup option **Layer Thickness**.

Number of Parts for Printing

This is the number of parts that are built at one time. By default, this is the maximum number of parts that can fit on the build plate. Users can override the default and specify this number with the setup option **Number of Parts per Build Plate**.

To calculate the default value, aPriori uses either true-part-shape or rectangular nesting calculations. The cost model assumes a border all around each part whose size, by default, is specified by the cost model variable **nestingAllowance** (5mm in starting point VPEs). Users can override the default with the setup option **Nesting Allowance**. aPriori assumes true-part-shape nesting by default, but rectangular nesting is used if you select an option *other than True-Part Shape Nesting* in the Material Utilization dialog.

With true-part-shape nesting, the cost engine uses an internal algorithm that considers multiple candidate nesting arrangements using a variety of part orientations. By default, the various orientations differ by an angle specified by the cost model variable **defaultUtilizationStepAngle** (90° in starting point VPEs). With the setup option **Step Angle for True-Part Shape Nesting**, users can specify a step angle for the cost engine to use in order to generate additional candidate orientations—smaller step angles result in the consideration of a greater number of candidate nesting arrangements (which increases costing time but may result in more efficient nesting). The algorithm chooses the optimal nesting arrangement from among the considered candidates.

With rectangular nesting, the cost model uses the steps below in order to determine the number of parts that can fit on the build plate.

- 3 Find the maximum number of lengthwise-oriented parts that fit on the build platform.

**rounddown (Machine Bed Length / (Part Length + (2 * Nesting Allowance))) *
rounddown (Machine Bed Width / (Part Width + (2 * Nesting Allowance)))**

(Lengthwise orientation means that the part's length is aligned with the platform's length and the part's width is aligned with the platform's width.)

- 4 Find the maximum number of widthwise-oriented parts that fit.

**rounddown (Machine Bed Length / (Part Width + (2 * Nesting Allowance))) *
rounddown (Machine Bed Width / (Part Length + (2 * Nesting Allowance)))**

(Widthwise orientation means that the part's width dimension is aligned with the platform's length and the part's length is aligned with the platform's width.)

- 5 Pick the larger of the values found in 1 and 2, above. This is the Number of Parts (unless it is 0, in which the Number of Parts is 1).

Material Cost Formulas for Printing

Material Cost includes the cost for the material used for the part. The cost of material used for support structures is included in Additional Direct Costs—see [Additional Direct Costs—Support Structures for Printing](#).

$$\text{Material Cost} = ((\text{Part Volume} * \text{Cost Per Volume}) / \text{Utilization}) / \text{Final Yield}$$

Material cost depends on the following:

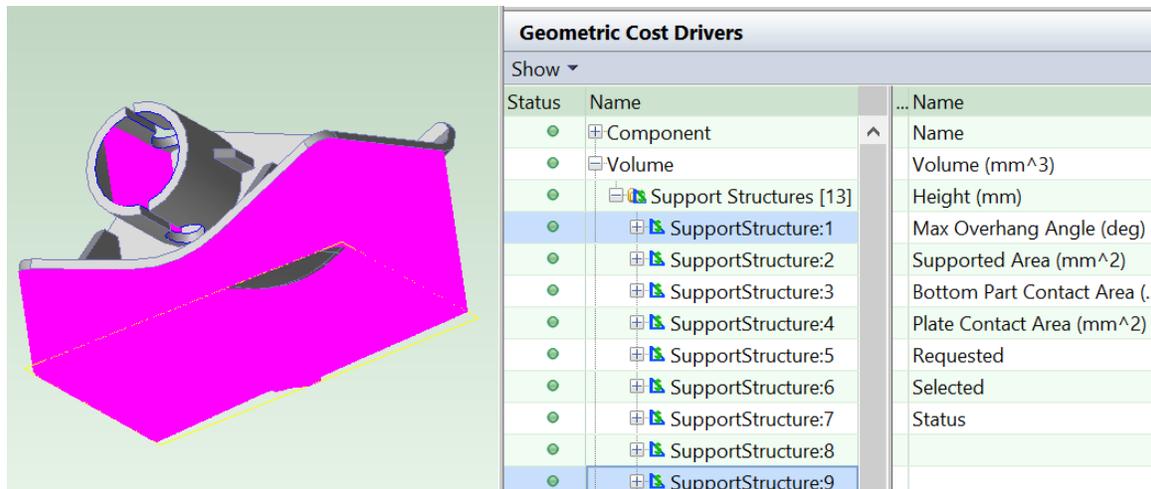
- Part volume (determined by geometry extraction)
- Cost per volume (see formula)
- Utilization: this is assumed to be 1, if the utilization mode is **Computed**.
- Final yield (see [Yield Formulas for Additive Manufacturing](#))

$$\text{Cost Per Volume} = \text{Material Density} * \text{Material Cost Per KG}$$

- Material density: for non-Default materials, this is specified by the material property **Density**. For the Default material, this is specified by cost model variable `printingDefaultMaterialDensity` (1185 kg/m³ in starting point VPEs).
- Material cost per kg: for non-Default materials, this is specified by the material property **Unit Cost**. For the Default material, this is specified by cost model variable `printingDefaultMaterialCost` (\$225 per kg in starting point VPEs).

Additional Direct Costs—Support Structures for Printing

Geometry extraction creates a number of GCDs to represent support structures, which support overhanging geometries, and provide a base that separates the part from the build platform.



The cost of support structures is accounted for as an additional direct cost. The material for support structures is different from the part material. Support material density and cost are determined as described for the Support Cost formula below. The cost model assumes that support structures include the following:

- Structure that separates the part from the build platform (which protects the part from damage when the operator scrapes the finished part off of the platform). By default, the height of this base structure is specified by the site variable `buildPlateOffset` (10mm in starting point VPEs). Users can override the default with the setup option `Base Plate: Support Structures Height`.

Note: if you use the setup option to override the default base height, this does *not* affect how the base is displayed in the Viewer and does *not* affect the values of support structure geometric properties displayed in the Geometric Cost Drivers pane. The override *is* used, however, in the calculation of support material cost.

- Structures to support overhanging geometries (which are removed once the part material is fully cured and can support itself). In starting point VPEs, the cost model assumes that support structures are required for all surfaces (with an exception noted below) that make an angle of less than 45 degrees with the build plate. The exception is a surface that forms a sufficiently short bridge. Administrators can customize the angle threshold with the site variable **maxSupportedOverhangAngle**.

Additional site variables control how many support structures are created for geometry that encompasses a range of angles with respect to the build plate (for example, an arch): **overhangAngularRangeDivisionNum** (2 in starting point VPEs) specifies the number of support structures created, starting at the point at which the angle is smallest and ending at the point at which the angle is **maxSupportedOverhangAngle**. One of these is between the point at which the angle is smallest and the point at which the angle is **minSupportedOverhangAngle** (35 degrees in starting point VPEs); and the remainder of the support structures are between the points at which the angles are **minSupportedOverhangAngle** and **maxSupportedOverhangAngle**.

The cost model currently only uses fully vertical supports. An overhang that might employ a slanted support is instead always handled in the cost model by a vertical support whose top and bottom are both attached to the part.

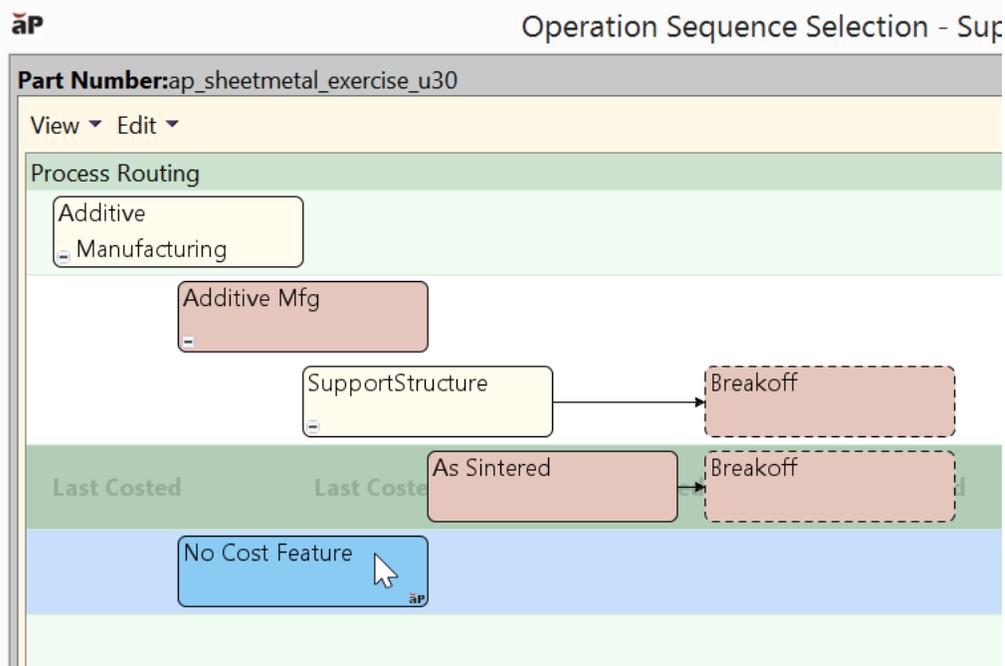
In some cases, geometry extraction may create supports that are inside of the part and cannot be removed.

Geometry extraction attempts to choose the height dimension of the part so as to minimize the volume of supports. The cost model assumes that the part is oriented with the height direction normal to the build plate. Users can override the choice of height dimension with the Build Direction tool—see [Using the Build Direction Tool to Orient the Part](#).

If a user considers a particular support structure unnecessary, they can manually assign the GCD to the No Cost operation: right-click on the GCD in the Manufacturing Process pane or Geometric Cost Drivers pane, and select Edit Operation....

Geometric Cost Drivers		
Status	Name	O... Name
●	Component	Name
●	Volume	Volume (mm ³)
●	Support Structures [4]	Height (mm)
●	SupportStructure:1	Max Overhang /
●	SupportStructure:2	Area
●	SupportStructure:3	Cor
●	SupportStructure:4	Ar
●	Holes	
●	Surfaces	
		Status

Then click No Cost operation in the Operation Sequence Selection dialog, and click OK.



In this case, costs associated with the support structure GCD will not be included.

Additional Direct Costs = Support Cost / Final Yield

Additional direct costs depends on the following:

- Support cost (see formula)
- Final yield (see [Yield Formulas for Additive Manufacturing](#))

Support Cost = Support Volume * Support Density * Support Cost Per KG

- Support volume (see formula).
- Support density (specified by the cost model variable `printingSupportMaterialDensity`—1050 kg/m³ in starting point VPEs)

- Support cost per kg (specified by the cost model variable **printingSupportMaterialCost**—\$250 in starting point VPEs)

$$\text{Support Volume} = ((\text{Support Model Volume} - \text{Default Base Support Volume}) + \text{Base Support Volume}) * \text{Lattice Factor}$$

Support volume depends on the following:

- Support model volume: this is the sum of the volumes of all the Support Structure GCDs. This may differ from the support volume to be used in the support cost calculation, because the actual volume of the support base may differ from the extracted volume.
- Default base support volume: This is the portion of the extracted volume that represents the base support. It is the product of the site variable **basePlateOffset** and the sum of the values of the property **Plate Contact Area** for all Support GCDs.
- Base support volume: this is the actual volume of the base support. It is the product of the actual base support height and the sum of the values of the property **Plate Contact Area** for all Support GCDs. By default, the actual base height is given by the site variable **basePlateOffset**, but users can override the default with the setup option **Base Plate: Support Structures Height**. The actual volume differs from the extracted volume when and only when the user overrides the default base height with the setup option.
- Lattice spacing factor: this factor reduces the volume in order to account for the possibility that each structure, rather than being solid, is actually composed of a lattice of material. The factor is specified by the cost model variable **printingLatticeSpacingFactor** (1 in starting point VPEs).

Laser Sintering Formulas

Formulas and calculations used by the Laser Sintering process are described in the following sections:

- Setup Formula for Laser Sintering
- Cycle Time Formulas for Laser Sintering
- Support Structure GCDs and Laser Sintering
- Number of Parts for Laser Sintering
- Material Cost and Utilization for Laser Sintering
- Additional Direct Costs for Laser Sintering

Setup Formula for Laser Sintering

$$\text{Amortized Batch Setup} = \frac{(\text{Setup Time} * (\text{Labor Rate} + \text{Direct Overhead Rate}))}{\text{Batch Size}}$$

Batch setup cost per part depends on the following:

- Setup time: by default, this is specified by the cost model variable **loadFileAndSpliceTime** (15 minutes in starting point VPEs). Users can override the default and specify the setup time with the setup option **Load and Splice Time**.
- Labor rate (specified by the machine property **Labor Rate**)
- Direct overhead rate (see **Direct and Indirect Overhead**)

- Batch size (specified in the **Production Scenario** screen of the Cost Guide)

Cycle Time Formulas for Laser Sintering

Cycle Time = Process Time * Adjustment Factor

Cycle time is the product of the following:

- Process time (see formula)
- Adjustment factor (specified by the cost model variable **cycleTimeAdjustmentFactor**). This factor is 1 in aPiori starting point VPEs. VPE administrators can modify **cycleTimeAdjustmentFactor** in order to adjust cycle times across processes within the current VPE.

Process Time = Preparation Time + (Part Time / Number of Parts) + Cool Time

Process time depends on the following:

- Preparation Time (see formula)
- Part time (see formula)
- Number of parts (see [Number of Parts for Laser Sintering](#))
- Cool Time (see formula)

Part Time = (Build Time * Number of Parts) + Layer Delay

Part time is the time to build all the parts on the build platform, and including the time spent putting fresh powder between layers. It depends on the following:

- Build time (see formula)
- Number of parts (see [Number of Parts for Laser Sintering](#), above)
- Layer delay: this is the time spent putting fresh powder between layers. See formula

Build Time = Part Volume / Solidification Rate

This is the time to build one part (not including the support base). It depends on the following:

- Part volume (determined by geometry extraction)
- Solidification rate (see formula)

Solidification Rate = Beam Diameter * Adjusted Layer Thickness * Scanning Speed

Solidification rate is the volume per unit time created by the sintering process. It is the product of the following:

- Beam diameter (specified by the machine property **Beam Diameter**)
- Adjusted layer thickness: by default, this is specified by the cost model variable **slsLayerThickness** (0.1mm in starting point VPEs). Users can override the default on a part-by-part basis with the setup option [Layer Thickness](#).
- Scanning speed (specified by the machine property **Scanning Speed**)

Layer Delay = (Layers - 1) * Layer Delay per Layer

Layer delay is the time spent putting fresh powder between layers. Powder is put on top of each layer except the last. This is the time spent for all the parts on the build platform. The total layer delay depends on the following:

- Layers: this is the number of layers in one vertical cross-section of the part. See formula.
- Layer delay per layer: this is the time to put powder on a single layer. It is specified by the machine property **Layer Delay**.

Layers = roundup ((Base Layers Height + Nest Bed Height) / Layer Thickness)

This is the distance in layers from the platform to the top of the parts in the build chamber. It depends on the following:

- Base layers height: the height of the buffer of material between platform and part. By default, this is specified by the cost model variable **slsBaseLayersHeight** (15mm in starting point VPEs). Users can override the default with the setup option [Base Powder Height](#).
- Nest bed height (see formula)
- Layer thickness: by default, this is specified by the cost model variable **slsLayerThickness** (0.1mm in starting point VPEs). Users can override the default on a part-by-part basis with the setup option [Layer Thickness](#).

Nest Bed Height = (Powder Height Fraction * Machine Bed Height) – Base Layers Height

This depends on the following:

- Powder height fraction: this is the value of the setup option [Powder Height As A Percentage Of Build Chamber Height](#). The default value is the fraction of the build chamber that would have to be occupied by powder in order to accommodate the default [Number of Parts for Laser Sintering](#).
- Machine bed height (specified by the machine property **Bed Height**)
- Base layers height: the height of the buffer of material between platform and part. By default, this is specified by the cost model variable **slsBaseLayersHeight** (15mm in starting point VPEs). Users can override the default with the setup option [Base Powder Height](#).

Preparation Time = (Prep Build Chamber Time + Heat Chamber Time) / Number of Parts

Preparation times depends on the following:

- Prep build chamber time: By default, this is specified by the cost model variable **slsPrepBuildChamber** (1200 seconds in starting point VPEs). Users can override the default with the setup option [Prepare Build Chamber Time](#).
- Heat chamber time: by default, this is specified by the cost model variable **slsHeatChamberTime** (4140 seconds in starting point VPEs). Users can override the default with the setup option [Heat Build Chamber Time](#).
- Number of parts (see [Number of Parts for Laser Sintering](#))

Cool Time = Cool Chamber Time / Number of Parts

Cool time depends on the following:

- Cool chamber time: by default, this is specified by the cost model variable **slsCoolChamberTime** (2180 seconds in starting point VPEs). User can override the default with the setup option [Cool Build Chamber Time](#).

- Number of parts (see [Number of Parts for Laser Sintering](#))

Support Structure GCDs and Laser Sintering

Geometry extraction creates a number of GCDs to represent support structures that are required for DMLS, SLA and Material Jetting routings (see [Support Structures for Metal Sintering](#), [Additional Direct Costs—Support Structures for Printing](#) and [Support Structures for Resin Curing](#)). But these GCDs have no effect on costing for SLS routings. With Laser Sintering, parts are built with a full surrounding of unsintered powder, so supports are unnecessary.

Number of Parts for Laser Sintering

This is the number of parts that are built at one time. By default, this is the maximum number of parts that can fit in the build chamber. Users can override the default and specify this number with the setup option [Number of Parts per Build Plate](#).

To calculate the default value, aPiori first uses either true-part-shape or rectangular nesting calculations in order to determine the number of parts that can fit on the build platform, arranged in the XY plane.

aPiori then calculates the number of vertical layers of n parts so arranged that can be accommodated by the height of the build chamber. The total number of parts that can fit in the build chamber is the product of n and the number of layers.

Note: Note that a *layer* of whole parts is different from a *layer* of sintered material created by a single pass over the build chamber (see, for example, [Cycle Time Formulas for Laser Sintering](#)).

The cost model assumes a border all around each part whose size, by default, is specified by the cost model variable **nestingAllowance** (5mm in starting point VPEs). Users can override the default with the setup option [Nesting Allowance](#).

aPiori assumes true-part-shape nesting by default, but rectangular nesting is assumed if you select an option *other than True-Part Shape Nesting* in the Material Utilization dialog.

With true-part-shape nesting, the cost engine uses an internal algorithm that considers multiple candidate nesting arrangements using a variety of part orientations. By default, the various orientations differ by an angle specified by the cost model variable **defaultUtilizationStepAngle** (90° in starting point VPEs). With the setup option [Step Angle for True-Part Shape Nesting](#), users can specify a step angle for the cost engine to use in order to generate additional candidate orientations—smaller step angles result in the consideration of a greater number of candidate nesting arrangements (which increases costing time but may result in more efficient nesting). The algorithm chooses the optimal nesting arrangement from among the considered candidates.

With rectangular nesting, the cost model uses the steps below in order to determine the number of parts in one layer of parts on the build platform.

- 1 Find the maximum number of lengthwise-oriented parts that fit on the build platform.

**rounddown (Machine Bed Length / (Part Length + (2 * Nesting Allowance))) *
rounddown (Machine Bed Width / (Part Width + (2 * Nesting Allowance)))**

(Lengthwise orientation means that the part's length is aligned with the platform's length and the part's width is aligned with the platform's width.)

- 2 Find the maximum number of widthwise-oriented parts that fit.

$$\text{rounddown}(\text{Machine Bed Length} / (\text{Part Width} + (2 * \text{Nesting Allowance}))) * \text{rounddown}(\text{Machine Bed Width} / (\text{Part Length} + (2 * \text{Nesting Allowance})))$$

(Widthwise orientation means that the part's width dimension is aligned with the platform's length and the part's length is aligned with the platform's width.)

- 3 Pick the larger of the values found in 1 and 2, above. This is the number of parts in one layer of parts on the build platform (unless it is 0, in which case the number of parts is 1).

With both nesting calculation methods, the number of layers of parts that can fit in the build chamber is the result of rounding down the quotient of the available chamber height and the height required by each part:

Number of Part Layers =

$$\text{rounddown}(\text{Available Chamber Height} / \text{Required Height per Part})$$

- Available chamber height: this is the difference between the machine property **Bed Height** and the height of the buffer of powder between the part and the build platform. By default, the height of this buffer is specified by the cost model variable **slsBaseLayersHeight** (15mm in starting point VPEs). Users can override the default with the setup option [Base Powder Height](#).
- Required height per part: this is the sum of the part **Height** and the [Nesting Allowance](#).

Material Cost and Utilization for Laser Sintering

Material Cost includes the cost for the material used for the part, as well as unrecoverable, thermally damaged material.

$$\text{Material Cost} = ((\text{Part Volume} * \text{Cost Per Volume}) / \text{Utilization}) / \text{Final Yield}$$

Material cost depends on the following:

- Part volume (determined by geometry extraction)
- Cost per volume (see formula)
- Utilization: this is assumed to be 1, if the utilization mode is **Computed**.
- Final yield (see [Yield Formulas for Additive Manufacturing](#))

$$\text{Cost Per Volume} = \text{Material Density} * \text{Material Cost Per KG}$$

Cost per volume is the product of the following:

- Material density: this is specified by the material property **Density**.
- Material cost per kg: this is specified by the material property **Unit Cost**.

$$\text{Utilization} = \text{Finish Mass} / \text{Rough Mass}$$

Utilization depends on the following:

- Finish mass: this is the mass of the finished part (volume times material density)
- Rough mass: this is the mass of material used per part (see formula)

$$\text{Rough Mass} = \text{Powder Loaded Mass} / (\text{Number of Parts} * \text{Number of Allowable Powder Cycles})$$

Rough mass depends on the following:

- Powdered loaded mass: this is the mass of the powder loaded into the machine chamber per run. See formula.
- Number of parts (see [Number of Parts for Laser Sintering](#))
- Number of allowable powder cycles: this is the total number of cycles for which unsintered powder can be used and re-used. By default, this is specified by the material property **Max Powder Cycles**. Users can override the default with the setup option [Number of Powder Cycles](#).

$$\text{Powder Loaded Mass} = \text{Powder Loaded Mass per Machine} + ((\text{Number of Allowable Powder Cycles} - 1) * \text{Virgin Powder Per Machine})$$

Powder loaded mass is the mass of the powder loaded into the machine chamber per run. It is the depends on the following:

- Powder loaded mass per machine (see formula)
- Number of allowable powder cycles: this is the total number of cycles for which unsintered powder can be used and re-used. By default, this is specified by the material property **Max Powder Cycles**. Users can override the default with the setup option [Number of Powder Cycles](#).
- Virgin powder per machine (see formula)

$$\text{Powder Loaded Mass Per Machine} = \text{Feed Rise Factor} * (\text{Feed Bed Length} * \text{Feed Bed Width} * (\text{Nest Bed Height} + \text{Base Layers Height})) * \text{Material Tapped Density}$$

Powder loaded mass is the mass of the powder loaded into the machine chamber per run. It depends on the following:

- Feed rise factor: specified by the cost model variable **slsPowderFeedRiseFactor** (2.25 in starting point VPEs).
- Feed bed length: specified by the machine property **Bed Length**.
- Feed bed width: specified by the machine property **Bed Width**.
- Nest bed height: see formula in [Cycle Time Formulas for Laser Sintering](#).
- Base layers height: the height of the buffer of material between the part and the build platform. By default, this specified by the cost model variable **slsBaseLayersHeight** (15mm in starting point VPEs). Users can override the default with the setup option [Base Powder Height](#).
- Material tapped density: value of the material property **Tapped Density**. This is the density of the powder in the build chamber before it is sintered.

$$\text{Virgin Powder per Machine} = \text{Powder Loaded Mass per Machine} - \text{Recycled Mass per Machine}$$

Virgin powder per machine is the difference between the following:

- Powder loaded mass per machine (see formula)
- Recycled mass per machine (see formula)

Recycled Mass per Machine = (Powder Loaded Mass per Machine – Solid Mass per Run) * Recycle Percentage

Recycled mass per machine depends on the following:

- Powder loaded mass per machine (see formula)
- Solid mass per run (see formula)
- Recycle percentage: specified by the material property **Recycle Percentage**. Users can specify a different value with the setup option **Powder Recycle Percentage**.

Solid Mass Per Run = Number Of Parts * (Material Density * Part Volume)

Solid mass per run is mass of the sintered material that has been solidified into parts. It is the product of the following:

- Number of parts (see [Number of Parts for Laser Sintering](#))
- Material density (specified by the material property **Density**)
- Part volume (specified by the GCD property **Volume**)

Additional Direct Costs for Laser Sintering

Additional Direct Costs = (Laser Cost + Nitrogen Cost) / Final Yield

Additional direct costs depend on the following:

- Laser cost (see formula)
- Nitrogen cost (see formula)
- Final yield (see [Yield Formulas for Additive Manufacturing](#))

Laser Cost = Laser Rate * Build Time

Laser cost depends on the following:

- Laser rate: this is the cost per unit time (specified by the machine property **Laser Cost Per Hour**)
- Build time (see formula in [Cycle Time Formulas for Laser Sintering](#))

Note that aPriori converts the times to hours for use in this formula.

Nitrogen Cost =

(Nitrogen Rate * Part Time * Nitrogen Cost Per Volume) / Number of Parts

Nitrogen cost is 0 for all machines that do not require an external source of Nitrogen (that is, whose machine property **Requires External Nitrogen** is **false**). Nitrogen cost depends on the following:

- Nitrogen rate: this is the volume per unit time required by the machine. It is specified in liters per hour by the machine property **Nitrogen Rate**.
- Part time (see formula in [Cycle Time Formulas for Laser Sintering](#))
- Nitrogen cost per volume (specified by the machine property **Nitrogen Cost**)
- Number of parts (see [Number of Parts for Laser Sintering](#))

Note that aPriori converts the times to hours for use in this formula.

Metal Sintering Formulas

Formulas and calculations used by the Metal Sintering process are described in the following sections:

- [Labor and Setup Formulas for Metal Sintering](#)
- [Cycle Time Formulas for Metal Sintering](#)
- [Number of Parts for Metal Sintering](#)
- [Material Cost Formulas for Metal Sintering](#)
- [Additional Direct Costs for Metal Sintering](#)
- [Support Structures for Metal Sintering](#)

Labor and Setup Formulas for Metal Sintering

Labor Cost = Labor Time * Labor Rate / Final Yield

Labor cost is a function of the following:

- Labor time (see formula below)
- Labor rate (specified by the machine property **Labor Rate**)
- Final yield (see [Yield Formulas for Additive Manufacturing](#))

Labor Time =

Powder Removal Time Per Part * Number of Operators * Labor Time Standard

Labor time is the product of the following:

- Powder removal time per part (see formula)
- Number of operators (specified by the machine property **Number of Operators**)
- Labor time standard: specified as the machine property **Labor Time Standard**. This multiplier is used to account for otherwise unaccounted for factors that affect labor time, such as operator fatigue or time spent by the operator for cleaning or maintenance.

Powder Removal Time Per Part = Total Powder Removal Time / Total Number of Parts

Labor time per part is the powder removal time amortized over the number of parts:

- Total powder removal time (see formula in [Cycle Time Formulas for Metal Sintering](#))
- Total number of parts (see [Number of Parts for Metal Sintering](#))

Amortized Batch Setup =

(Setup Time * (Labor Rate + Direct Overhead Rate)) / Batch Size

Batch setup cost per part depends on the following:

- Setup time: by default, this is specified by the cost model variable **loadFileAndSpliceTime** (15 minutes in starting point VPEs). Users can override the default and specify the setup time with the setup option [Load and Splice Time](#).
- Labor rate (specified by the machine property **Labor Rate**)
- Direct overhead rate (see [Direct and Indirect Overhead](#))

- Batch size (specified in the **Production Scenario** screen of the Cost Guide)

Cycle Time Formulas for Metal Sintering

Cycle Time = Process Time * Adjustment Factor

Cycle time is the product of the following:

- Process time (see formula)
- Adjustment factor (specified by the cost model variable **cycleTimeAdjustmentFactor**). This factor is 1 in aPiori starting point VPEs. VPE administrators can modify **cycleTimeAdjustmentFactor** in order to adjust cycle times across processes within the current VPE.

Process Time = Preparation Time + Support Time + Part Time + Recoat Time + Powder Removal Time per Part + Cool Time

Process time is the sum of the following:

- Preparation time (see formula)
- Support time (see formula)
- Part time (see formula)
- Recoat time (see formula)
- Powder removal time per part (see formula)
- Cool time (see formula)

Preparation Time = (Fit Build Plate Time + Purge Time + Heat Chamber Time) / Total Number of Parts

Preparation time depends on the following:

- Fit build plate time: by default, this is specified by the cost model variable **dmlsFitBuildPlateTime** (1200 seconds in starting point VPEs). Users can override the default with the setup option [Fitting Build Plate Time](#).
- Purge time: this is the time to fill the build chamber with inert gas. By default, this is specified by the cost model variable **dmlsPurgeDuration** (1800 seconds in starting point VPEs). Users can override the default with the setup option [Inert Gas Purge Time](#).
- Heat chamber time: this is the time to heat the gas in the build chamber. By default, this is specified by the cost model variable **dmlsHeatChamberTime** (3600 seconds in starting point VPEs). Users can override the default with the setup option [Build Chamber Heat Time](#).
- Total number of parts (see [Number of Parts for Metal Sintering](#))

Support Time = Support Volume / Sinter Rate

This is the time to create the support structures. Support time depends on the following

- Support volume (see formula).
- Sinter rate (see formula)

Support Volume = ((Support Model Volume - Default Base Support Volume) + Base Support Volume) * Lattice Factor

Support volume depends on the following:

- Support model volume: this is the sum of the volumes of all the Support Structure GCDs. This may differ from the support volume to be used in the cycle time and rough mass calculations, because the actual volume of the support base may differ from the extracted volume—see [Support Structures for Metal Sintering](#).
- Default base support volume: This is the portion of the extracted volume that represents the base support. It is the product of the site variable **basePlateOffset** and the sum of the values of the property **Plate Contact Area** for all Support GCDs.
- Base support volume: this is the actual volume of the base support. It is the product of the actual base support height and the sum of the values of the property **Plate Contact Area** for all Support GCDs. The actual base height is determined by the base-removal process included in the current routing or any override specified with the setup option Base Plate: Support Structures Height--see [Support Structures for Metal Sintering](#).
- Lattice spacing factor: this factor reduces the volume in order to account for the fact that each structure, rather than being solid, is actually composed of a lattice of material. The factor is specified by the cost model variable **dmlsLatticeSpacingFactor** (0.4 in starting point VPEs)

$$\text{Sinter Rate} = \text{Beam Diameter} * \text{Powder Layer Thickness} * \text{Scanning Speed} * \text{Number of Lasers}$$

This is the volume of material per unit time sintered by the machine. Sinter rate is the product of the following:

- Beam diameter (specified by the machine property **Beam Diameter**)
- Powder layer thickness: by default, this is halfway between the machine's minimum and maximum layer thickness (specified by the machine properties **Minimum Layer Thickness** and **Maximum Layer Thickness**). Users can override the default with the setup option [Layer Thickness](#).
- Scanning speed: distance per unit time at which the beam moves across the build platform during sintering, specified by the machine property **Scanning Speed**.
- Num lasers: specified by the machine property **Number of Lasers**.

$$\text{Part Time} = \text{Part Volume} / \text{Sinter Rate}$$

This is the sintering time for the part (not including support structures). Part time depends on the following

- Part volume (determined by geometry extraction)
- Sinter rate (see formula, above)

$$\text{Recoat Time} = (\text{Number of Layers} * \text{Recoat Time per Layer}) / \text{Total Number of Parts}$$

This is the time per part for putting fresh powder between layers. Powder is put on top of each layer except the last. Recoat time depends on the following:

- Number of layers (see formula)
- Recoat time per layer (see formula)
- Total number of parts (see [Number of Parts for Metal Sintering](#))

Number of Layers = roundup ((Part Height + Base Support Height) / Powder Layer Thickness) - 1

This is the number of layers on top of which powder is spread (powder is put on top of each layer except the last). It depends on the following:

- Part height (determined by geometry extraction)
- Base support height: this is the height of the buffer of material that separates the part from the build platform (which protects the part from damage when the operator scrapes the finished part off of the platform). The height is determined based on the base-removal process included in the current routing or any override specified with the setup option [Base Plate: Support Structures Height](#)--see [Support Structures for Metal Sintering](#).
- Powder layer thickness: by default, this is halfway between the machine's minimum and maximum layer thickness (specified by the machine properties **Minimum Layer Thickness** and **Maximum Layer Thickness**). Users can override the default with the setup option [Layer Thickness](#).

Recoat Time per Layer = (Machine Bed Length / Recoating Speed Over) + (Machine Bed Length / Recoating Speed Return)

This is the time for the recoater blade to travel across the machine bed, plus the time for the blade to return to its starting point. Recoat time per layer depends on the following:

- Machine bed length (specified by the machine property **Bed Length**)
- Recoating speed over: the speed at which the recoater blade travels across the machine bed to spread the powder. By default, it is specified by the cost model variable **dmlsPowderRecoatSpeedOver** (76mm/sec in starting point VPEs). Users can override the default with the setup option [Recoating Layer Speed Over](#).
- Recoating speed return: the speed at which the recoater blade returns to its starting point after spreading the powder. By default, it is specified by the cost model variable **dmlsPowderRecoatSpeedReturn** (200mm/sec in starting point VPEs). Users can override the default with the setup option [Recoating Layer Speed Return](#).

Total Powder Removal Time = Loose Powder Bulk / Suction Removal Rate

Total powder removal time depends on the following:

- Loose powder bulk (see formula)
- Suction removal rate. This is specified by the cost model variable **powderVacuumRemovalRate** (300kg/hr in starting point VPEs)

Loose Powder Bulk = Powder Loaded Mass – Solid Mass per Run

The mass of loose bulk powder (powder to be removed) at the end of a cycle is the difference between the following:

- Powder loaded mass (see formula)
- Solid mass per run (see formula)

$$\text{Powder Loaded Mass} = \text{Feed Rise Factor} * \text{Feed Bed Length} * \text{Feed Bed Width} * (\text{Part Height} + \text{Base Support Height}) * \text{Material Tapped Density}$$

This is the mass of the powder initially loaded into the machine. It includes both powder that will be made solid during the machine cycle and powder that will remain in the powdered state. It is calculated based on density of the material in a powdered state, the volume of the build chamber (excluding the portion of the chamber above the top of the part), and an adjustment factor that ensures that the powder feed platform rises enough to cover the build platform. Powder loaded mass is the product of the following:

- Feed rise factor: specified by the cost model variable **dmlsPowderFeedRiseFactor** (2.25 in starting point VPEs).
- Feed bed length (specified by the machine property **Bed Length**)
- Feed bed width (specified by the machine property **Bed Width**)
- Base support height: this is the height of the buffer of material that separates the part from the build platform (which protects the part from damage when the operator scrapes the finished part off of the platform). The height is determined based on the base-removal process included in the current routing or any override specified with the setup option **Base Plate: Support Structures Height**--see [Support Structures for Metal Sintering](#).
- Part height (determined by geometry extraction)
- Material tapped density (specified by the material property **Tapped Density**)

$$\text{Solid Mass per Run} = \text{Solid Mass per Part} * \text{Total Number of Parts}$$

Solid mass per run is the product of the following:

- Solid mass per part (see formula)
- Total number of parts (see [Number of Parts for Metal Sintering](#))

$$\text{Solid Mass per Part} = \text{Part Mass} + \text{support Mass}$$

Solid mass per part is the sum of the following:

- Part mass (part volume times material density)
- Support mass (support volume times material density—see the formula for [Support Volume](#) above)

$$\text{Cool Time} = \text{Cool Chamber Time} / \text{Number of Parts}$$

Cool time per part depends on the following:

- Cool chamber time: by default, this is specified by the cost model variable **dmlsCoolChamberTime** (3600 seconds in starting point VPEs). Users can override the default with the setup option **Build Chamber Cool Time**.
- Number of parts (see [Number of Parts for Metal Sintering](#))

Number of Parts for Metal Sintering

This is the number of parts that are built at one time. By default, this is the maximum number of parts that can fit on the build plate. Users can override the default and specify this number with the setup option **Number of Parts per Build Plate**.

To calculate the default value, aPriori uses either true-part-shape or rectangular nesting calculations. The cost model assumes a border all around each part whose size, by default, is specified by the cost model variable **nestingAllowance** (5mm in starting point VPEs). Users can override the default with the setup option **Nesting Allowance**. aPriori assumes true-part-shape nesting by default, but rectangular nesting is used if you select an option *other than True-Part Shape Nesting* in the Material Utilization dialog.

With true-part-shape nesting, the cost engine uses an internal algorithm that considers multiple candidate nesting arrangements using a variety of part orientations. By default, the various orientations differ by an angle specified by the cost model variable **defaultUtilizationStepAngle** (90° in starting point VPEs). With the setup option **Step Angle for True-Part Shape Nesting**, users can specify a step angle for the cost engine to use in order to generate additional candidate orientations—smaller step angles result in the consideration of a greater number of candidate nesting arrangements (which increases costing time, but may result in more efficient nesting). The algorithm chooses the optimal nesting arrangement from among the considered candidates. (The number of parts is bounded above by the size of a production batch, as specified in the Cost Guide.)

With rectangular nesting, the cost model uses the steps below in order to determine the number of parts that can fit on the build plate.

- 1 Find the maximum number of lengthwise-oriented parts that fit on the build platform.

$$\text{rounddown}(\text{Machine Bed Length} / (\text{Part Length} + (2 * \text{Nesting Allowance}))) * \text{rounddown}(\text{Machine Bed Width} / (\text{Part Width} + (2 * \text{Nesting Allowance})))$$

(Lengthwise orientation means that the part's length is aligned with the platform's length and the part's width is aligned with the platform's width.)

- 2 Find the maximum number of widthwise-oriented parts that fit.

$$\text{rounddown}(\text{Machine Bed Length} / (\text{Part Width} + (2 * \text{Nesting Allowance}))) * \text{rounddown}(\text{Machine Bed Width} / (\text{Part Length} + (2 * \text{Nesting Allowance})))$$

(Widthwise orientation means that the part's width dimension is aligned with the platform's length and the part's length is aligned with the platform's width.)

- 3 Pick the larger of the values found in 1 and 2, above. This is the Number of Parts (unless it is 0, in which the Number of Parts is 1).

Material Cost Formulas for Metal Sintering

Material Cost =

$$((\text{Part Mass} * \text{Material Cost per Unit Mass}) / \text{Utilization}) / \text{Final Yield}$$

Material cost depends on the following:

- Part mass (product of material density and part volume)
- Material cost per unit mass: for non-Default materials, this is specified by the material property **Unit Cost**. For the Default material, this is specified by cost model variable **dmlsDefaultMaterialCost** (\$152 per kg in starting point VPEs).
- Utilization (see formula)
- Final yield (see [Yield Formulas for Additive Manufacturing](#))

Utilization = Finish Mass / Rough Mass

Utilization depends on finish mass (part mass) and rough mass (total, non-reusable material required for one part):

- Finish mass (product of part volume and material density)
- Rough mass (see formula)

Rough Mass = Finish Mass + Support Mass + Waste Mass Per Part + Powder Recycling Limit Disposal Mass

Rough mass is the sum of the following:

- Finish mass (product of part volume and material density)
- Support mass: this is the total support volume per part times material density. See the formula for Support Volume in [Cycle Time Formulas for Metal Sintering](#).
- Waste mass per part (see formula)
- Powder recycling limit disposal mass. This is the per-part amount of powder that has been recycled the maximum allowable number of times, and so must be disposed of. See formula.

Waste Mass Per Part = (Powder Loss to Process Inefficiency * Material Density * (Part Volume + Support Volume)) + (Powder Trapped in Support Structures * Material Tapped Density * Support Volume)

Waste mass is the mass of unrecoverable material lost to inefficiencies in the process (for example, material lost due to thermal damage) plus the mass of support-structure material that cannot be removed from the part (for example, because it is inside of an enclosed void). It depends on the following:

- Powder loss to process inefficiency: this is the fraction of part and support volume that is lost due to process inefficiency. It is specified by the cost model variable `dmlsPowderLossToProcessInefficiency` (0.4 in starting point VPEs).
- Material density
- Part volume (determined by geometry extraction)
- Support volume (see formula in [Cycle Time Formulas for Metal Sintering](#))
- Powder trapped in support structures: this is the fraction of support volume that cannot be removed from the part (for example, because it is inside of an enclosed void). It is specified by the cost model variable `dmlsPowderTrappedInSupportStructures` (0.25 in starting point VPEs).
- Material tapped density (specified by the material property `Tapped Density`)

Powder Recycling Limit Disposal Mass = (Powder Loaded Mass - (Waste Mass per Run + Solid Mass Per Run)) / (Num Allowable Powder Cycles * Total Number of Parts)

This is the per-part amount of powder that has been recycled the maximum allowable number of times, and so must be disposed of. It depends on the following:

- Powder loaded mass: see formula in [Cycle Time Formulas for Metal Sintering](#).

- Waste Mass per Run: this is the product of waste mass per part (see formula above) and the total number of parts per run (see [Number of Parts for Metal Sintering](#)).
- Solid mass per run: see formula in [Cycle Time Formulas for Metal Sintering](#).
- Num allowable powder cycles: specified by the cost model variable `dmlsNumberAllowablePowderUsageCycles` (20 in starting point VPEs).
- Total number of parts (see [Number of Parts for Metal Sintering](#))

Additional Direct Costs for Metal Sintering

Additional Direct Costs = Nitrogen Cost / Final Yield

Additional direct costs depend on the following:

- Nitrogen cost (see formula)
- Final yield (see [Yield Formulas for Additive Manufacturing](#))

Nitrogen Cost = (Nitrogen Rate * Construction Time * Nitrogen Cost Per Volume) / Number of Parts

Nitrogen cost depends on the following:

- Nitrogen rate: this is the volume per unit time required by the machine. It is specified in liters per hour by the machine property **Nitrogen Rate**.
- Construction time (see formula)
- Nitrogen cost per volume (specified by the machine property **Nitrogen Cost**)
- Number of parts (see [Number of Parts for Metal Sintering](#))

Note that aPriori converts the times to hours for use in this formula.

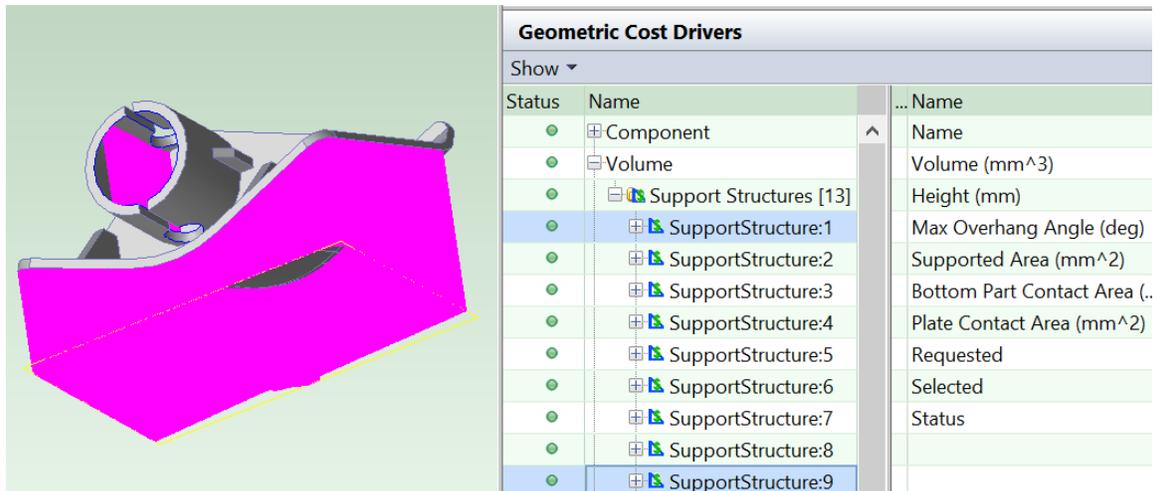
Construction Time = Process Time – Preparation Time + ((Purge Time + Heat Chamber Time) / Number of Parts)

Construction time depends on the following:

- Process time (see formula in [Cycle Time Formulas for Metal Sintering](#))
- Preparation time (see formula in [Cycle Time Formulas for Metal Sintering](#))
- Purge time (see formula in [Cycle Time Formulas for Metal Sintering](#))
- Heat chamber time: this is the time to heat the gas in the build chamber. By default, this is specified by the cost model variable `dmlsHeatChamberTime` (3600 seconds in starting point VPEs). Users can override the default with the setup option [Build Chamber Heat Time](#).

Support Structures for Metal Sintering

Geometry extraction creates a number of GCDs to represent support structures, which support overhanging geometries, and provide a base that separates the part from the build platform.



In particular, the structures include the following:

- Structure that separates the part from the build platform (which protects the part from damage when the operator scrapes the finished part off of the platform). For purposes of geometry extraction, the height of this base structure is specified by the site variable **buildPlateOffset** (10mm in starting point VPEs). This offset helps determine how the base is displayed in the Viewer as well as the values of support structure geometric properties displayed in the Geometric Cost Drivers pane.

But for the purposes of cost model calculations, the default base height depends on the base-structure-removal process included in the current routing. The routing includes one of the following processes. Each base-removal process has an associated cost model variable that specifies the default base height for that process:

- Manual Tool Base Removal: **baseSupportHeightManualRemoval** (10mm in starting point VPEs).
- Power Tool Base Removal: **baseSupportHeightPowerRemoval** (10mm in starting point VPEs).
- Wire EDM (in the Machining process group): **baseSupportHeightWireEDM** (1mm in starting point VPEs).

Users can override the default base height with the setup option **Base Plate: Support Structures Height**; such an override applies regardless of the base-structure-removal process in the current routing.

- Structures to support overhanging geometries (which are removed once the part material is fully cured and can support itself). In starting point VPEs, the cost model assumes that support structures are required for all surfaces (with an exception noted below) that make an angle of less than 45 degrees with the build plate. The exception is a surface that forms a sufficiently short bridge. Administrators can customize the angle threshold with the site variable **maxSupportedOverhangAngle**.

Additional site variables control how many support structures are created for geometry that encompasses a range of angles with respect to the build plate (for example, an arch): **overhangAngularRangeDivisionNum** (2 in starting point VPEs) specifies the number of support structures created, starting at the point at which the angle is smallest and ending at the point at which the angle is

maxSupportedOverhangAngle. One of these is between the point at which the angle is smallest and the point at which the angle is **minSupportedOverhangAngle** (35 degrees in starting point VPEs); and the remainder of the support structures are between the points at which the angles are **minSupportedOverhangAngle** and **maxSupportedOverhangAngle**.

The cost model currently only uses fully vertical supports. An overhang that might employ a slanted support is instead always handled in the cost model by a vertical support whose top and bottom are both attached to the part.

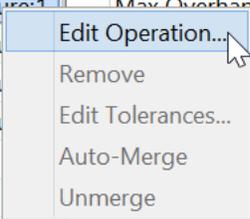
In some cases, geometry extraction may create supports that are inside of the part and cannot be removed.

Geometry extraction attempts to choose the height dimension of the part so as to minimize the volume of supports. The cost model assumes that the part is oriented with the height direction normal to the build plate. Users can override the choice of height dimension with the Build Direction tool—see [Using the Build Direction Tool to Orient the Part](#).

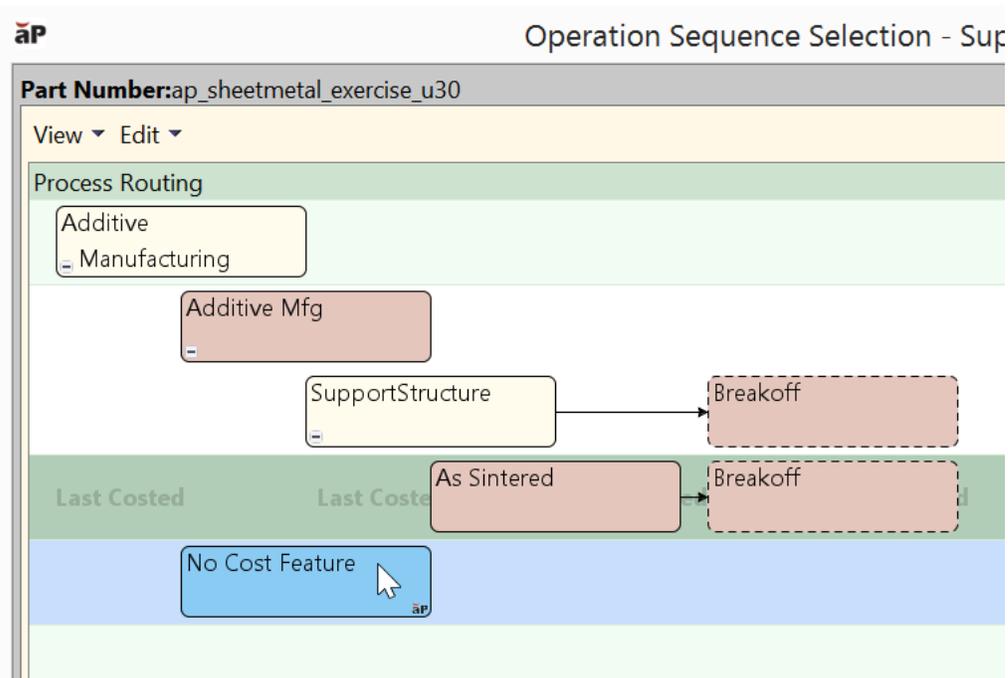
The support structures are made with the same material as the part.

If a user considers a particular support structure unnecessary, they can manually assign the GCD to the No Cost operation: right-click on the GCD in the Manufacturing Process pane or Geometric Cost Drivers pane, and select Edit Operation....

Geometric Cost Drivers		
Show ▾		
Status	Name	O... Name
●	⊕ Component	Name
●	⊖ Volume	Volume (mm ³)
●	⊖ Support Structures [4]	Height (mm)
●	⊕ SupportStructure:1	Max Overhang /
●	⊕ SupportStructure:2	Area
●	⊕ SupportStructure:3	Cor
●	⊕ SupportStructure:4	Ar
●	⊕ Holes	
●	⊕ Surfaces	
		Status



Then click No Cost operation in the Operation Sequence Selection dialog, and click OK.



In this case, costs associated with the support structure GCD will not be included.

Resin Curing Formulas

Formulas and calculations used by the Resin Curing process are described in the following sections:

- Setup Formula for Resin Curing
- Cycle Time Formulas for Resin Curing
- Number of Parts for Resin Curing
- Support Structures for Resin Curing
- Material Cost and Utilization for Resin Curing
- Additional Direct Costs for Resin Curing

Setup Formula for Resin Curing

$$\text{Amortized Batch Setup} = \frac{\text{Setup Time} * (\text{Labor Rate} + \text{Direct Overhead Rate})}{\text{Batch Size}}$$

Batch setup cost per part depends on the following:

- Setup time: by default, this is specified by the cost model variable **loadFileAndSpliceTime** (15 minutes in starting point VPEs). Users can override the default and specify the setup time with the setup option Load and Splice Time.
- Labor rate (specified by the machine property **Labor Rate**)
- Direct overhead rate (see [Direct and Indirect Overhead](#))
- Batch size (specified in the **Production Scenario** screen of the Cost Guide)

Cycle Time Formulas for Resin Curing

Cycle Time = Process Time * Adjustment Factor

Cycle time is the product of the following:

- Process time (see formula)
- Adjustment factor (specified by the cost model variable **cycleTimeAdjustmentFactor**). This factor is 1 in aPriori starting point VPEs. VPE administrators can modify **cycleTimeAdjustmentFactor** in order to adjust cycle times across processes within the current VPE.

Process Time = (Part Time + Support Time + Preprocessing Time) / Number of Parts

Process time depends on the following:

- Part time (see formula)
- Support time (see formula)
- Preprocessing time: this is the time to orient the part or parts on the build platform. By default, it is specified by the cost model variable **slaPreprocessingTime** (1200 seconds in starting point VPEs). Users can override the default on a part-by-part basis with the setup option **Preprocessing Time**.
- Number of parts: this is the number of parts that are built at once, that is, the number of parts on the build platform at one time--see [Number of Parts for Resin Curing](#).

Part Time = (Build Time * Number of Parts) + Layer Delay + Wipe Time

Part time is the time to build all the parts on the build platform, not including time to build the support base (see the formula for **Support Time**), and including the time spent between layers (including layers of the support base) to move the build platform in preparation for the next layer. It also includes time after each layer to apply a fresh layer of resin. It depends on the following:

- Build time (see formula)
- Number of parts (see [Number of Parts for Laser Sintering](#), above)
- Layer delay: time spent putting fresh powder between layers. See formula.
- Wipe time: time apply fresh layers of resin for all the parts on the build platform. See formula.

Build Time = Part Volume / Solidification Rate

This is the time to build one part (not including the support base). It depends on the following:

- Part volume (determined by geometry extraction)
- Solidification rate (see formula)

Solidification Rate = Beam Diameter * Adjusted Layer Thickness * Scanning Speed

Solidification rate is the volume per unit time created by the sintering process. It is the product of the following:

- Beam diameter (specified by the machine property **Beam Diameter**)

- Adjusted layer thickness: by default, this is specified by the cost model variable **slaStandardLayerResolution** (0.1mm in starting point VPEs) or the cost model variable **slaHighLayerResolution** (0.05mm in starting point VPEs), depending on the setting the option Layer Resolution. Users can override the default on a part-by-part basis with the setup option [Layer Thickness](#).
- Scanning speed (specified by the machine property **Scanning Speed**)

Layer Delay = (Layers - 1) * Layer Delay per Layer

Layer delay is the time spent between layers moving the build platform in preparation for a new layer. This is the time spent for all the parts on the build platform. The total layer delay depends on the following:

- Layers: this is the number of layers in one vertical cross-section of the part and support base. See formula.
- Layer delay per layer: this is the time to put powder on a single layer. It is specified by the machine property **Layer Delay**.

Layers = roundup (Part Height + Base Support Structure Height) / Adjusted Layer Thickness

This is the distance in layers from the platform to the top of the part, that is, the number of layers in one vertical cross-section of the sintered material (the part together with the buffer of material between platform and part). It depends on the following:

- Part height (specified by geometry extraction)
- Base support structure height: this is the height of the buffer of material that separates the part from the build platform. The buffer protects the part from damage when the operator scrapes the finished part off of the platform. By default, the buffer height is specified by the site variable **buildPlateOffset** (10mm in starting point VPEs). User can override the default with the setup option [Base Plate: Support Structures Height](#).
- Adjusted layer thickness: by default, this is specified by the cost model variable **slaStandardLayerResolution** (0.1mm in starting point VPEs) or the cost model variable **slaHighLayerResolution** (0.05mm in starting point VPEs), depending on the setting the option Layer Resolution. Users can override the default on a part-by-part basis with the setup option [Layer Thickness](#).

Wipe Time = (Bed Width / Wiper Speed) * Layers

This is the time apply fresh layers of resin for all the parts on the build platform. Wipe time depends on the following:

- Bed width (specified by the machine property **Bed Width**)
- Wiper speed (specified by the machine property **Wiper Speed**)
- Layers: this is the number of layers in one vertical cross-section of the part and support base. See formula.

Support Time = (Support Volume / Support Solidification Rate) * Number of Parts

This is the time to build the bases that separate the parts from the build platform. It depends on the following:

- Support volume: this is the volume of the supports structures required for the part (see [Support Structures for Resin Curing](#)). See formula.

- Support Solidification rate (see formula below)
- Number of parts: this is the number of parts on the build platform at one time (see [Number of Parts for Resin Curing](#))

Support Volume = ((Support Model Volume - Default Base Support Volume) + Base Support Volume) * SLA Support Volume Fraction

Support volume depends on the following:

- Support model volume: this is the sum of the volumes of all the Support Structure GCDs. This may differ from the support volume to be used in the cycle time and rough mass calculations, because the actual volume of the support base may differ from the extracted volume.
- Default base support volume: This is the portion of the extracted volume that represents the base support. It is the product of the site variable **basePlateOffset** and the sum of the values of the property **Plate Contact Area** for all Support GCDs.
- Base support volume: this is the actual volume of the base support. It is the product of the actual base support height and the sum of the values of the property **Plate Contact Area** for all Support GCDs. By default, the actual base height is given by the site variable **basePlateOffset**, but users can override the default with the setup option [Base Plate: Support Structures Height](#). The actual volume differs from the extracted volume when and only when the user overrides the default base height with the setup option.
- SLA support volume fraction: this factor reduces the volume in order to account for the fact that each structure, rather than being solid, is actually composed of a lattice of material. The factor is specified by the cost model variable **slaSupportVolumeFraction** (0.05 in starting point VPEs).

Support Solidification Rate = Beam Diameter * Support Layer Thickness * Scanning Speed

Solidification rate is the volume per unit time created by the sintering process. It is the product of the following:

- Beam diameter (specified by the machine property **Beam Diameter**)
- Support layer thickness: this is specified by the cost model variable **slaSupportLayerThickness** (0.1mm in starting point VPEs).
- Scanning speed (specified by the machine property **Scanning Speed**)

Number of Parts for Resin Curing

This is the number of parts that are built at one time. By default, this is the maximum number of parts that can fit on the build plate. Users can override the default and specify this number with the setup option [Number of Parts for Resin Curing](#).

To calculate the default value, aPriori uses either true-part-shape or rectangular nesting calculations. The cost model assumes a border all around each part whose size, by default, is specified by the cost model variable **nestingAllowance** (5mm in starting point VPEs). Users can override the default with the setup option [Nesting Allowance](#). aPriori assumes true-part-shape nesting by default, but rectangular nesting is used if you select an option *other than True-Part Shape Nesting* in the Material Utilization dialog.

With true-part-shape nesting, the cost engine uses an internal algorithm that considers multiple candidate nesting arrangements using a variety of part orientations. By default,

the various orientations differ by an angle specified by the cost model variable **defaultUtilizationStepAngle** (90° in starting point VPEs). With the setup option Step Angle for True-Part Shape Nesting, users can specify a step angle for the cost engine to use in order to generate additional candidate orientations—smaller step angles result in the consideration of a greater number of candidate nesting arrangements (which increases costing time, but may result in more efficient nesting). The algorithm chooses the optimal nesting arrangement from among the considered candidates.

With rectangular nesting, the cost model uses the steps below in order to determine the number of parts that can fit on the build plate.

- 1 Find the maximum number of lengthwise-oriented parts that fit on the build platform.

$$\text{rounddown} (\text{Machine Bed Length} / (\text{Part Length} + (2 * \text{Nesting Allowance}))) * \text{rounddown} (\text{Machine Bed Width} / (\text{Part Width} + (2 * \text{Nesting Allowance})))$$

(Lengthwise orientation means that the part's length is aligned with the platform's length and the part's width is aligned with the platform's width.)

- 2 Find the maximum number of widthwise-oriented parts that fit.

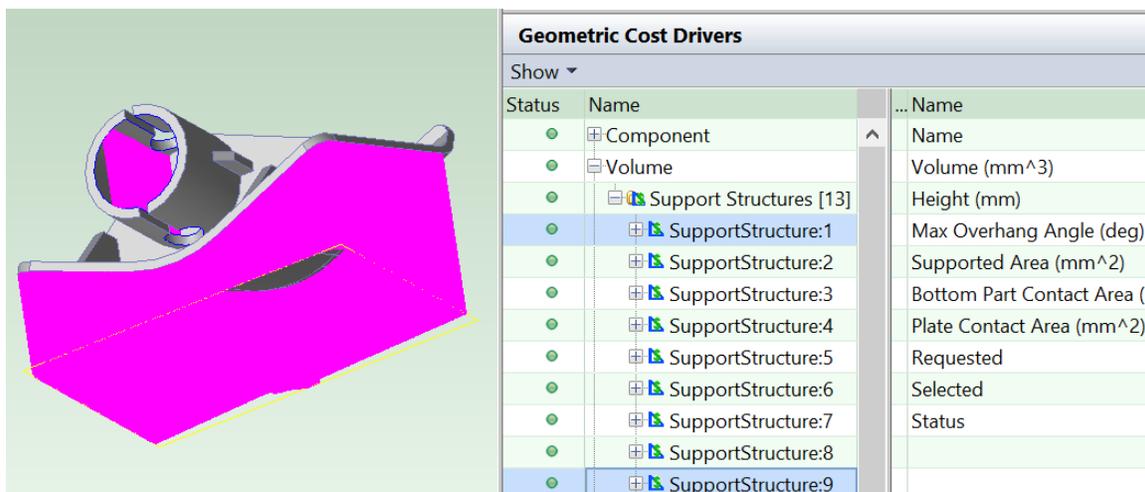
$$\text{rounddown} (\text{Machine Bed Length} / (\text{Part Width} + (2 * \text{Nesting Allowance}))) * \text{rounddown} (\text{Machine Bed Width} / (\text{Part Length} + (2 * \text{Nesting Allowance})))$$

(Widthwise orientation means that the part's width dimension is aligned with the platform's length and the part's length is aligned with the platform's width.)

- Pick the larger of the values found in 1 and 2, above. This is the Number of Parts (unless it is 0, in which the Number of Parts is 1).

Support Structures for Resin Curing

Geometry extraction creates a number of GCDs to represent support structures, which support overhanging geometries, and provide a base that separates the part from the build platform.



In particular, the structures include the following:

- Structures that separate the part from the build platform (which protects the part from damage when the operator scrapes the finished part off of the platform). By

default, the height of these base structures is specified by the site variable **buildPlateOffset** (10mm in starting point VPEs). Users can override the default with the setup option [Base Plate: Support Structures Height](#).

Note: if you use the setup option to override the default base height, this does *not* affect how the base is displayed in the Viewer and does *not* affect the values of support structure geometric properties displayed in the Geometric Cost Drivers pane. The override *is* used, however, in the calculation of cycle time and rough mass.

- Structures to support overhanging geometries (which are removed once the part material is fully cured and can support itself). In starting point VPEs, the cost model assumes that support structures are required for all surfaces (with an exception noted below) that make an angle of less than 45 degrees with the build plate. The exception is a surface that forms a sufficiently short bridge. Administrators can customize the angle threshold with the site variable **maxSupportedOverhangAngle**.

Additional site variables control how many support structures are created for geometry that encompasses a range of angles with respect to the build plate (for example, an arch): **overhangAngularRangeDivisionNum** (2 in starting point VPEs) specifies the number of support structures created, starting at the point at which the angle is smallest and ending at the point at which the angle is **maxSupportedOverhangAngle**. One of these is between the point at which the angle is smallest and the point at which the angle is **minSupportedOverhangAngle** (35 degrees in starting point VPEs); and the remainder of the support structures are between the points at which the angles are **minSupportedOverhangAngle** and **maxSupportedOverhangAngle**.

The cost model currently only uses fully vertical supports. An overhang that might employ a slanted support is instead always handled in the cost model by a vertical support whose top and bottom are both attached to the part.

In some cases, geometry extraction may create supports that are inside of the part and cannot be removed.

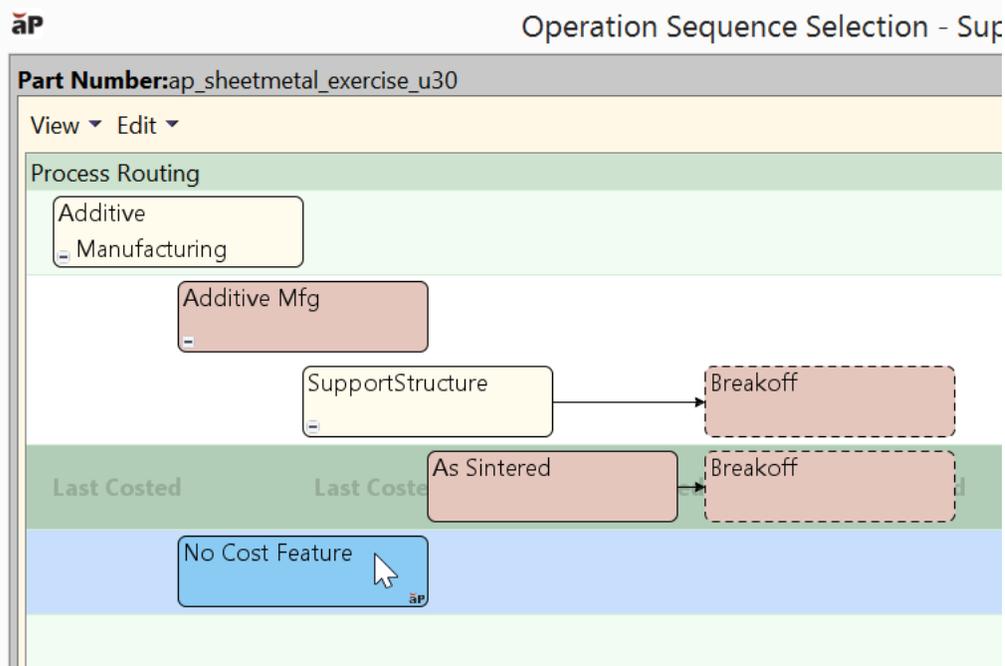
Geometry extraction attempts to choose the height dimension of the part so as to minimize the volume of supports. The cost model assumes that the part is oriented with the height direction normal to the build plate. Users can override the choice of height dimension with the Build Direction tool—see [Using the Build Direction Tool to Orient the Part](#).

The structures are made with the same material as the part, but the layer thickness can differ (see the formula for Support Solidification Rate in [Cycle Time Formulas for Resin Curing](#)). Support structure material is not recoverable.

If the user considers a particular support structure unnecessary, they can manually assign the GCD to the No Cost operation: right-click on the GCD in the Manufacturing Process pane or Geometric Cost Drivers pane, select Edit Operation....

Geometric Cost Drivers		
Status	Name	O... Name
●	⊕ Component	Name
●	⊖ Volume	Volume (mm^3)
●	⊖ Support Structures [4]	Height (mm)
●	⊕ SupportStructure:1	Max Overhang /
●	⊕ SupportStructure:2	Area
●	⊕ SupportStructure:3	Cor
●	⊕ SupportStructure:4	Ar
●	⊕ Holes	
●	⊕ Surfaces	
		Status

Then click No Cost operation in the Operation Sequence Selection dialog, and click OK.



In this case, costs associated with the support structure GCD will not be included.

Material Cost and Utilization for Resin Curing

Material Cost includes the cost for the material used for the part.

$$\text{Material Cost} = ((\text{Part Volume} * \text{Cost Per Volume}) / \text{Utilization}) / \text{Final Yield}$$

Material cost depends on the following:

- Part volume (determined by geometry extraction)
- Cost per volume (see formula)
- Utilization (see formula)
- Final yield (see Yield Formulas for Additive Manufacturing)

Cost Per Volume = Material Density * Material Cost Per KG

- Material density: this is specified by the material property **Density**.
- Material cost per kg: this is specified by the material property **Unit Cost**.

Utilization = Finish Mass / Rough Mass

Utilization depends on the following:

- Finish mass: this is the mass of the finished part (volume times material density)
- Rough mass: this is the mass of material used per part (see formula)

Rough Mass = Finish Mass + Support Mass

Rough mass depends on the following:

- Finish mass (part volume times material density)
- Support mass: see formula in [Cycle Time Formulas for Resin Curing](#).

Additional Direct Costs for Resin Curing

Additional direct costs include laser replacement costs.

Additional Direct Costs = Laser Cost / Final Yield

Additional direct costs depend on the following:

- Laser cost (see formula)
- Final yield (see [Yield Formulas for Additive Manufacturing](#))

Laser Cost = Laser Rate * (Build Time + Support Time)

Laser cost depends on the following:

- Laser rate: this is the cost per unit time (specified by the machine property **Laser Cost Per Hour**)
- Build time (see formula in [Cycle Time Formulas for Resin Curing](#))
- Support Time (see formula in [Cycle Time Formulas for Resin Curing](#))

Note that aPiori converts the times to hours for use in this formula.

Breakoff Formulas

Cycle Time = Process Time * Adjustment Factor

Cycle time is the product of the following:

- Process time: this is the sum of the process times for each support structure (see formula).
- Adjustment factor (specified by the cost model variable **cycleTimeAdjustmentFactor**). This factor is 1 in aPiori starting point VPEs. VPE administrators can modify **cycleTimeAdjustmentFactor** in order to adjust cycle times across processes within the current VPE.

Process Time per Support Structure = Positioning Time + Removal Time

Process time per structure is the sum of the following:

- Positioning time: this is the time spent positioning the tool prior to breaking off the top of the support structure, plus the time spent positioning the tool prior to breaking off the bottom of the support structure (except for DMLS supports that are connected to the base plate—this connection is severed by a separate, base-removal process).

Each time is specified by the cost model variable **handBreakoffPositioningTime** (3 seconds in starting point VPEs). So, except for DMLS supports connected to the base plate, the positioning time per support structure is twice the value of the cost model variable. For DMLS supports connected to the base plate, the positioning time per support structure is equal to the value of the cost model variable.

- Removal time: depends on the area of contact between the support structure and the part or build plate (see formula).

Removal Time = Support Contact Area / Hand Breakoff Rate

Removal time depends on the following:

- Hand breakoff rate: area per unit time, looked up by process (DMLS, Material Jetting, Stereolithography) in the lookup table **tblHandBreakoffRate**.

Process Name	Hand Breakoff Rate (mm ² / s)
Direct Metal Laser Sintering	10.00
Material Jetting	200.00
Stereolithography	25.00

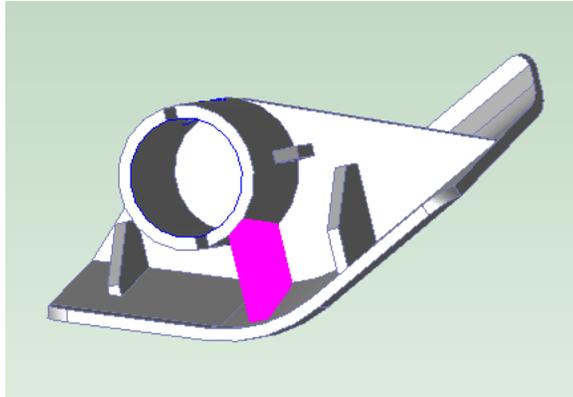
If the lookup fails, the breakoff rate is specified by the cost model variable **handBreakoffRate** (10mm²/sec in starting point VPEs).

- Support contact area: for all supports *except* DMLS supports, this is the total surface area of the both the following:
 - Regions of contact between the support structure and the part
 - Regions of contact between the support structure and the build platform.

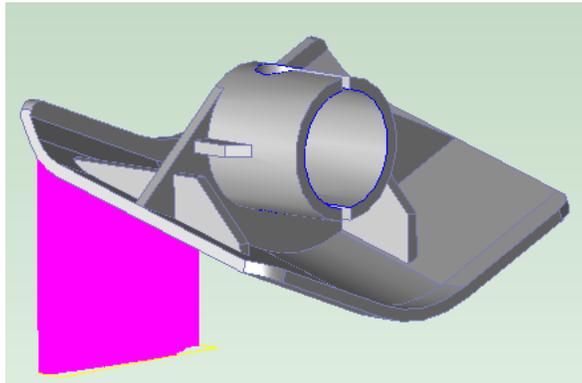
For DMLS routings, this is the surface area of the region of contact between the support structure and the part. (The region of contact between the support structure and the build platform are handled by a different, base-removal process, with DMLS routings.)

For support structures whose bottom is connected to the build plate, the area of contact between the support and the part is the geometric property **Supported Area**, and the area of contact between the support and the build plate is **Plate Contact Area**. For support structures whose bottom is connected to the part, the contact area is the sum of the geometric properties **Supported Area** and **Bottom Part Contact Area**.

The following image shows a support (in purple) whose top and bottom are both connected to the part:



The following image shows a support whose top is connected to the part and whose bottom is connected to the build platform:



If the total contact area for a support is 0 (for example, due to a modelling error), removal time is the value of the cost model variable **handBreakOffTime** (5 seconds in starting point VPEs).

Manual Tool Base Removal Formulas

Cycle Time = Process Time * Adjustment Factor

Cycle time is the product of the following:

- Process time: this is the sum of the process times for each support structure that is in contact with the build platform (see formula).
- Adjustment factor (specified by the cost model variable **cycleTimeAdjustmentFactor**). This factor is 1 in aPriori starting point VPEs. VPE administrators can modify **cycleTimeAdjustmentFactor** in order to adjust cycle times across processes within the current VPE.

Process Time per Support Structure = Positioning Time + Removal Time

Process time per structure is the sum of the following:

- Positioning time: this is the time spent positioning the tool prior to disconnecting the bottom of the support structure. Each time is specified by the cost model variable **handBreakoffPositioningTime** (3 seconds in starting point VPEs).
- Removal time: depends on the area of contact between the support structure and the build plate (see formula).

Removal Time = Support Contact Area / Hand Breakoff Rate

Removal time depends on the following:

- Hand breakoff rate: area per unit time, looked up by process (DMLS, Material Jetting, Stereolithography) in the lookup table **tblHandBreakoffRate**.

Process Name	Hand Breakoff Rate (mm ² / s)
Direct Metal Laser Sintering	10.00
Material Jetting	200.00
Stereolithography	25.00

If the lookup fails, the breakoff rate is specified by the cost model variable **handBreakoffRate** (10mm²/sec in starting point VPEs).

- Support contact area: this is the surface area of the region of contact between the support structure and the build plate, which is the value of the geometric properties **Bottom Part Contact Area**. (Regions of contact between the support structure and the part are handled by the Breakoff process.)

Power Tool Base Removal Formulas

Cycle Time = Process Time * Adjustment Factor

Cycle time is the product of the following:

- Process time: this is the sum of the process times for each support structure that is in contact with the build platform (see formula).
- Adjustment factor (specified by the cost model variable **cycleTimeAdjustmentFactor**). This factor is 1 in aPriori starting point VPEs. VPE administrators can modify **cycleTimeAdjustmentFactor** in order to adjust cycle times across processes within the current VPE.

Process Time per Support Structure = Positioning Time + Removal Time

Process time per structure is the sum of the following:

- Positioning time: this is the time spent positioning the tool prior to disconnecting the bottom of the support structure. Each time is specified by the cost model variable **handBreakoffPositioningTime** (3 seconds in starting point VPEs).
- Removal time: depends on the area of contact between the support structure and the build plate (see formula).

Removal Time = Support Contact Area / Breakoff Rate

Removal time depends on the following:

- Breakoff rate: area per unit time, specified by the machine property **Cutting Rate**. If the property is not specified for the current machine, the breakoff rate is given by the cost model variable **handBreakoffRate** (10mm²/sec in starting point VPEs).
- Support contact area: this is the surface area of the region of contact between the support structure and the build plate, which is the value of the geometric properties **Bottom Part Contact Area**. (Regions of contact between the support structure and the part are handled by the Breakoff process.)

Cleaning Formulas

Cycle Time = Process Time * Adjustment Factor

Cycle time is the product of the following:

- Process time: this is bounded below by the cost model variable **minCleaningTime** (60 seconds in starting point VPEs). Calculated process time (see formula below) is used if it exceeds this lower bound.
- Adjustment factor (specified by the cost model variable **cycleTimeAdjustmentFactor**). This factor is 1 in aPiori starting point VPEs. VPE administrators can modify **cycleTimeAdjustmentFactor** in order to adjust cycle times across processes within the current VPE.

Calculated Process Time = Clean Time + Reorient Time

Process time depends on the following:

- Clean time (see formula)
- Reorient time (see formula)

Clean Time = Surface Cleaning Area * Surface Cleaning Rate

Clean time is the product of the following:

- Surface cleaning area: this is the surface area of the part.
- Surface cleaning rate: this is specified by the machine property **Plastic Cleaning Rate** for materials with cut code 41, 42, 51, or 52; for all other materials it is specified by the machine property **Metal Cleaning Rate**.

Reorient Time = Number of Handling Operators * Handling Time per Operator

Load Time is the product of the following:

- Number of handling operators: this is looked up by weight in the lookup table **tblHandlingTimes**. Part weight is material density times part volume (blank area times blank thickness).
- Handling time per operator: this is interpolated from values looked up by part weight in **tblHandlingTimes**. Part weight is material density times part volume (blank area times blank thickness).

Part Curing Formulas

Part Curing formulas and calculations are covered in the following sections:

- Cycle Time Formula
- Elapsed Cure Time
- Number of Parts for Part Curing
- Additional Direct Costs for Part Curing

Cycle Time Formula

Cycle Time = Process Time * Adjustment Factor

Cycle time is the product of the following:

- Process time (see formula)

- Adjustment factor (specified by the cost model variable **cycleTimeAdjustmentFactor**). This factor is 1 in aPiori starting point VPEs. VPE administrators can modify **cycleTimeAdjustmentFactor** in order to adjust cycle times across processes within the current VPE.

Process Time = Elapsed Cure Time / Number of Parts

Process time depends on the following:

- Elapsed cure time (see [Elapsed Cure Time](#))
- Number of parts (see [Number of Parts for Part Curing](#))

Elapsed Cure Time

The cost model uses the steps below to determine elapsed cure time:

- 1 Estimate the elapsed cure time based on part *surface area*. The cost model uses an empirically derived linear function of surface area.
- 2 Estimate the elapsed cure time based on part *volume*. The cost model uses an empirically derived linear function of volume.
- 3 Elapsed Cure Time is the larger of the following:
 - Result of step 1 (area-based estimate)
 - Result of step 2 (volume-based estimate)

unless this is greater than the maximum cure time as specified by the cost model variable **curingMaxCureTime** (1800 seconds in starting point VPEs), in which case Elapsed Cure Time is **curingMaxCureTime**.

Number of Parts for Part Curing

This is the number of parts that can be cured at one time, that is, the maximum number of parts that satisfy both the following:

- Space constraint: they can all fit in the curing oven. The cost model assumes rectangular nesting, with a border around each part specified by the cost model variable **nestingAllowance** (5mm in starting point VPEs).
- Mass constraint: their total mass is no greater than the machine property **Maximum Mass**.

By default, the cost model uses the steps below in order to determine this number. Users can override the default value with the setup option [Number of Parts](#).

- 1 Find the maximum number of lengthwise-oriented parts that fit in the oven.

rounddown (Machine Bed Length / (Part Length + (2 * Nesting Allowance))) * rounddown (Machine Bed Width / (Part Width + (2 * Nesting Allowance)))

(Lengthwise orientation means that the part's length is aligned with the platform's length and the part's width is aligned with the platform's width.)

- 2 Find the maximum number of widthwise-oriented parts that fit.

$$\text{rounddown} (\text{Machine Bed Length} / (\text{Part Width} + (2 * \text{Nesting Allowance}))) * \\ \text{rounddown} (\text{Machine Bed Width} / (\text{Part Length} + (2 * \text{Nesting Allowance})))$$

(Widthwise orientation means that the part's width dimension is aligned with the platform's length and the part's length is aligned with the platform's width.)

- 3 Pick the larger of the values found in 1 and 2, above. This is the maximum number of parts that satisfy the space constraint (unless it is 0, in which case the maximum number of parts that satisfy the space constraint is 1).
- 4 Find the maximum number of parts that satisfy the mass constraint:

$$\text{rounddown} (\text{Machine Maximum Mass} / \text{Part Mass})$$
- 5 The Number of Parts is the smaller of the following two values:
 - Result of step 3 (maximum number of parts that satisfy the space constraint)
 - Result of step 4 (maximum number of parts that satisfy the mass constraint)

Additional Direct Costs for Part Curing

$$\text{Additional Direct Costs} = \text{Nitrogen Cost} / \text{Final Yield}$$

Additional direct costs depend on the following:

- Nitrogen cost (see formula)
- Final yield (see [Yield Formulas for Additive Manufacturing](#))

$$\text{Nitrogen Cost} = \text{Nitrogen Used} * \text{Nitrogen Cost Per Volume}$$

Nitrogen cost is the product of the following:

- Nitrogen used: if the current machine requires nitrogen, this is the product the elapsed cure time (see [Elapsed Cure Time](#)) and the nitrogen consumption rate as specified by the machine property **Nitrogen Cost**. The machine property **Requires Nitrogen** indicates whether the machine requires nitrogen.
- Nitrogen cost per volume (specified by the machine property **Nitrogen Cost**)

Sieving Formulas

$$\text{Cycle Time} = \text{Process Time} * \text{Adjustment Factor}$$

Cycle time is the product of the following:

- Process time (see formula)
- Adjustment factor (specified by the cost model variable **cycleTimeAdjustmentFactor**). This factor is 1 in aPiori starting point VPEs. VPE administrators can modify **cycleTimeAdjustmentFactor** in order to adjust cycle times across processes within the current VPE.

$$\text{Process Time} = \text{Powder Sieving Time per Run} / \text{Number of Parts}$$

This is the time per part to sieve the powder into bottles after it is removed from the machine. Process time depends on the following:

- Powder sieving time per run: by default, this is specified by the cost model variable **powderSieveTimePerRun** (900 seconds in starting point VPEs. Users can override the default with the setup option **Sieving Time per Run**).
- Number of parts (see **Number of Parts for Metal Sintering**)

Powder Loading Formulas

Cycle Time = Process Time * Adjustment Factor

Cycle time is the product of the following:

- Process time (see formula)
- Adjustment factor (specified by the cost model variable **cycleTimeAdjustmentFactor**). This factor is 1 in aPriori starting point VPEs. VPE administrators can modify **cycleTimeAdjustmentFactor** in order to adjust cycle times across processes within the current VPE.

Process Time = Load Time / Number of Parts

This is the time per part to load metal powder into the powder chamber. Process time depends on the following:

- Load time: by default, this is specified by the cost model variable **dmlsPowderLoadTime** (300 seconds in starting point VPEs. Users can override the default with the setup option **Powder Loading Time**).
- Number of parts (see **Number of Parts for Metal Sintering**)

User Inputs for Additive Manufacturing

Users can provide inputs to the costing process through the use of a number of setup options, as well as through the use of the Build Direction tool in the Viewer toolbar.

These are described in the following sections:

- [Using the Build Direction Tool to Orient the Part](#)
- [Top-level Setup Option](#)
- [Printing Setup Options](#)
- [Laser Sintering Options](#)
- [Metal Sintering Options](#)
- [Resin Curing Options](#)
- [Part Curing Option](#)
- [Sieving Option](#)
- [Powder Loading Option](#)

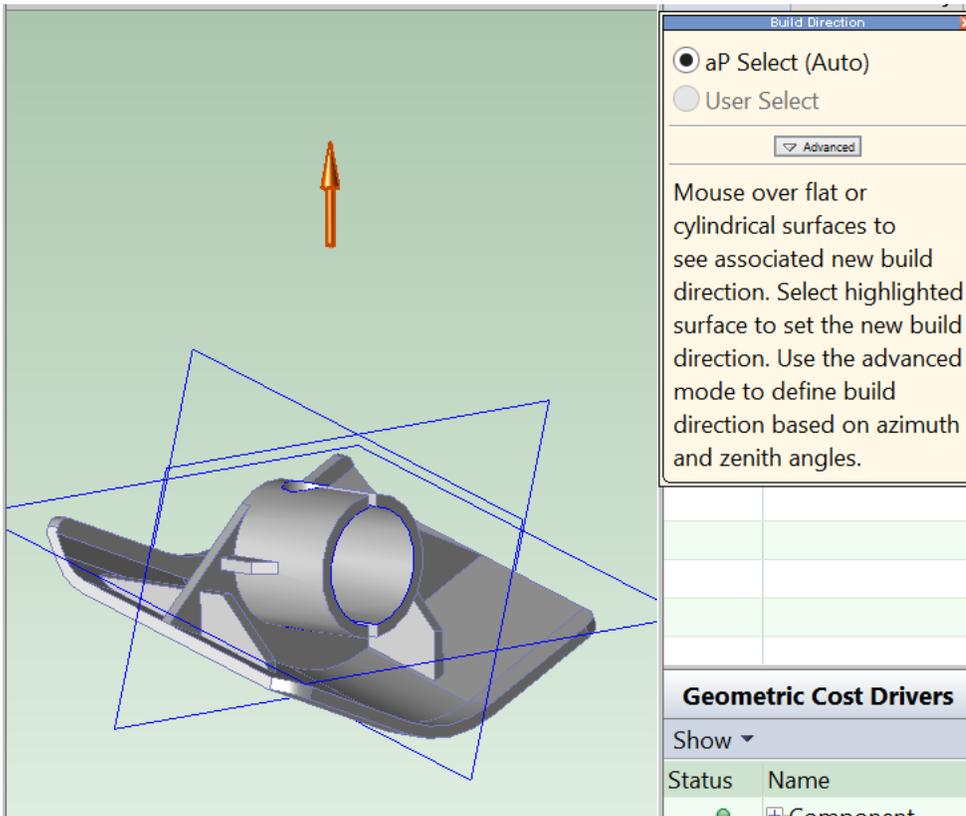
Using the Build Direction Tool to Orient the Part

Geometry extraction attempts to determine the part's likely orientation on the build platform. The part's orientation affects machine feasibility, build time, and material use.

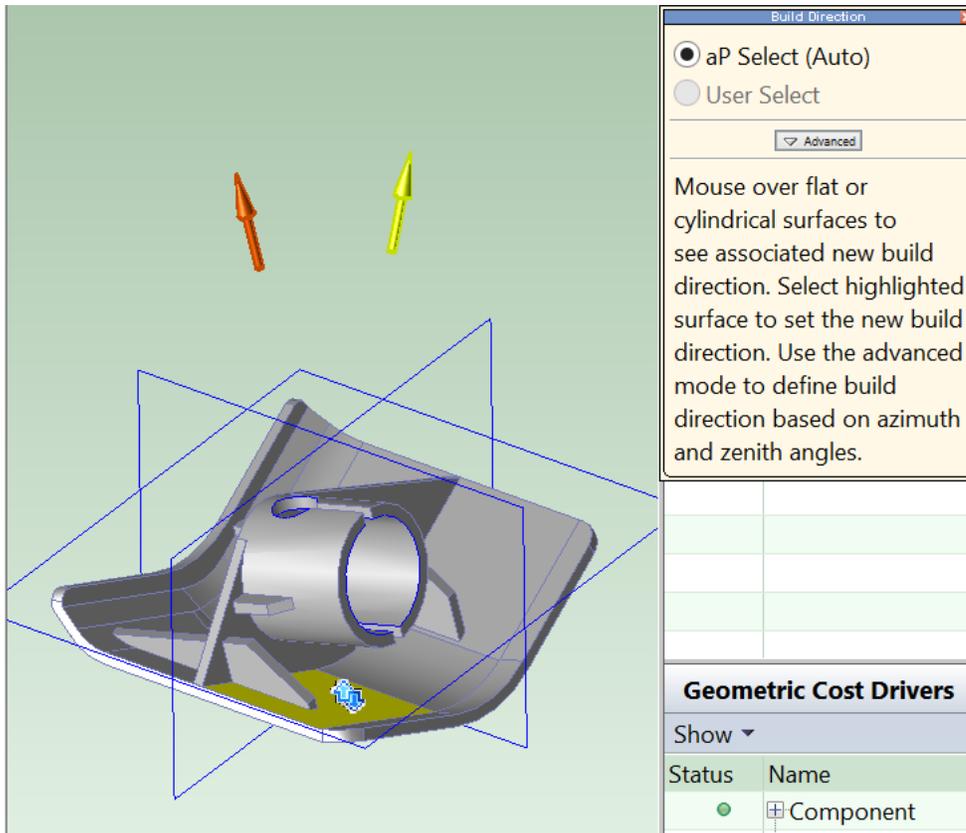
By default, aPriori generally chooses an orientation that minimizes the volume of required support structures (see [Additional Direct Costs—Support Structures](#), [Support Structures for Metal Sintering](#) or [Support Structures for Resin Curing](#)). In any case in which you do not want to use the default orientation, you can specify an orientation explicitly.

Follow these steps to specify the part's orientation:

- 1 Select the Build Direction tool  from the Viewer toolbar. The direction that is currently *upwards* for the oriented part is indicated by an amber arrow.



- 2 Choose a flat or cylindrical surface that is normal to the direction you want to be upwards for the oriented part: in the Viewer, hover over a surface that is normal to the direction you want to be upwards. The surface is highlighted, and a yellow arrow appears indicating the normal. Click to designate the normal as upwards.



You can also hover over the bounding box midlines—in blue above—in order to highlight directions; and you can click to select them. In addition, you can click the Advanced button in the Build Direction dialog, and specify upwards based on azimuth and zenith angles.

Note: Changing the build direction triggers recosting.

Note that the choice of part orientation determines which dimension of the part's bounding box is the height dimension, which affects various feasibility and cost calculations.

Top-level Setup Option

The Additive Manufacturing routing node provides the [Minimum Layer Thickness Check](#) setup option:

Minimum Layer Thickness Check

By default, the Material Jetting, SLS, DMLS, and SLA processes are feasible regardless of the layer thickness required to build the part. With this setup option, you can override the default on a part-by-part, and impose a minimum layer thickness constraint on process feasibility. See [Process Feasibility for Additive Manufacturing](#).

Printing Setup Options

For the 3D Printing routing, you can specify the following process setup options:

- Layer Thickness

- Nesting Allowance
- Step Angle for True-Part Shape Nesting
- Number of Parts per Build Plate
- Print Head Travel Type
- Number of Print Head Passes
- Base Plate: Support Structures Height
- Preprocessing Time
- Load and Splice Time

Layer Thickness

By default, this is specified by the machine property **Layer Thickness**. Users can override the default on a part-by-part basis with this setup option. See [Printing Formulas](#).

Nesting Allowance

By default, the space allowance around nested parts is specified by the cost model variable **nestingAllowance** (5mm in starting point VPEs). Users can override the default nesting allowance with this setup option. See [Cycle Time Formulas for Printing](#).

Step Angle for True-Part Shape Nesting

With true-part-shape nesting, the cost engine uses an internal algorithm that considers multiple candidate nesting arrangements using a variety of part orientations. By default, the various orientations differ by an angle specified by the cost model variable **defaultUtilizationStepAngle** (90° in starting point VPEs).

With this setup option, users can specify a step angle for the cost engine to use in order to generate additional candidate orientations—smaller nesting angles result in the consideration of a greater number of candidate nesting arrangements (which increases costing time, but may result in more efficient nesting).

Note that when the user specifies a step angle, the default candidate orientations are still included for consideration.

See [Number of Parts for Printing](#).

Number of Parts per Build Plate

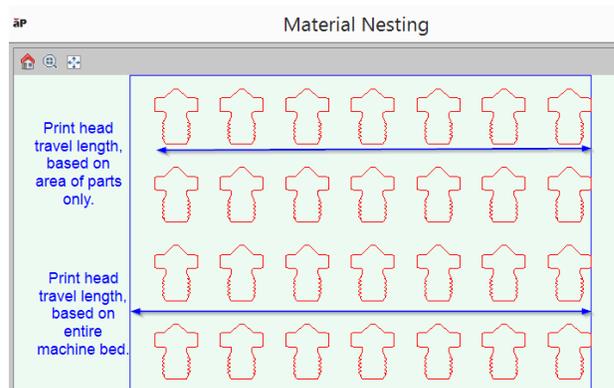
By default, this is the maximum number of parts that can fit on the build platform, with a border around each part whose width is specified by the cost model variable **nestingAllowance** (5mm in starting point VPEs) or the setup option [Nesting Allowance](#). With the setup option **Number of Parts**, users can override the default on a part-by-part basis, and specify a number of parts. See [Number of Parts for Printing](#).

Note that when you override the default with this setup option, the Material Nesting diagram can no longer be displayed.

Print Head Travel Type

By default, the cost model assumes that during each swipe, the print head travels the length of the array of nested parts (that is, the length of the smallest build-plate-aligned

rectangle that encloses all the parts). With this setup option, users can override the default and specify that the print head travels the entire length of the machine bed.



The print head travel type affects the evaluation of the [Cycle Time Formulas for Printing](#).

Number of Print Head Passes

This is the number of times the print head travels the nesting length or machine bed length before moving in the width direction. By default, the number is specified by the cost model variable **defaultNumPrintHeadPasses** (2 in starting point VPEs). Users can override the default with this setup option. See [Cycle Time Formulas for Printing](#).

Base Plate: Support Structures Height

By default, this is specified by the site variable **basePlateOffset** (10mm in starting point VPEs). Users can override the default with this setup option. See [Machine Feasibility for Printing and Additional Direct Costs—Support Structures for Printing](#).

Note: if you use the setup option to override the default base height, this does *not* affect how the base is displayed in the Viewer and does *not* affect the values of support structure geometric properties displayed in the Geometric Cost Drivers pane. The override *is* used, however, in the determination of machine feasibility and support material cost.

Preprocessing Time

By default, the time per part to orient the part or parts on the build platform is specified by the cost model variable **printingPreprocessingTime** (1200 seconds in starting point VPEs). Users can override the default on a part-by-part basis with this setup option. See [Cycle Time Formulas for Printing](#).

Load and Splice Time

This option controls the time to load the part model into the machine software and splice it into layers. By default, the time is specified by the cost model variable **loadFileAndSpliceTime** (0.25 hours in starting point VPEs). Users can override the default with this option. See the formula for Amortized Batch Setup in [Setup Formula for Printing](#).

Laser Sintering Options

For the Selective Laser Sintering routing, you can specify the following process setup options:

- Layer Thickness
- Nesting Allowance
- Step Angle for True-Part Shape Nesting
- Number of Parts per Build Plate
- Powder Height As A Percentage Of Build Chamber Height
- Load and Splice Time
- Base Powder Height
- Prepare Build Chamber Time
- Heat Build Chamber Time
- Cool Build Chamber Time
- Powder Recycle Percentage
- Number of Powder Cycles

Layer Thickness

By default, this is specified by the cost model variable **slsLayerThickness** (0.1mm in starting point VPEs). Users can override the default on a part-by-part basis with this setup option. See [Cycle Time Formulas for Laser Sintering](#).

Nesting Allowance

By default, the space allowance all around nested parts is specified by the cost model variable **nestingAllowance** (5mm in starting point VPEs). Users can override the default nesting allowance with this setup option. See [Number of Parts for Laser Sintering and Cycle Time Formulas for Laser Sintering](#).

Step Angle for True-Part Shape Nesting

With true-part-shape nesting, the cost engine uses an internal algorithm that considers multiple candidate nesting arrangements using a variety of part orientations. By default, the various orientations differ by an angle specified by the cost model variable **defaultUtilizationStepAngle** (90° in starting point VPEs).

With this setup option, users can specify a step angle for the cost engine to use in order to generate additional candidate orientations—smaller nesting angles result in the consideration of a greater number of candidate nesting arrangements (which increases costing time, but may result in more efficient nesting).

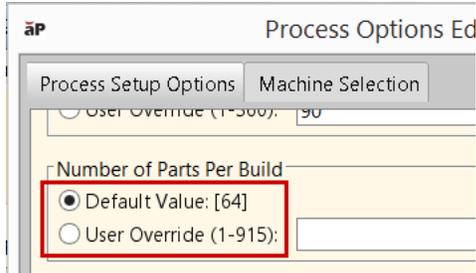
Note that when the user specifies a step angle, the default candidate orientations are still included for consideration.

See [Number of Parts for Laser Sintering](#).

Number of Parts per Build Plate

By default, this is the maximum number of parts that can fit in the build chamber, based on aPriori's rectangular or true-part nesting algorithm. See [Number of Parts for Laser Sintering](#) for detailed information on the calculation of the default number of parts. Users can override the default and specify a number with this setup option.

Note that the values you can enter are bounded above by the maximum number of parts that can fit in the build chamber, assuming (as is impossible) that there is no nesting allowance and that the parts are perfectly tessellated so as to occupy the entire powder nest bed (see the formula for Nest Bed Height in [Cycle Time Formulas for Laser Sintering](#)). In other words, the values you can enter are bounded above by the ratio of powder volume (excluding base powder) to part volume.



Note that when you override the default with this setup option, the Material Nesting diagram can no longer be displayed.

Powder Height As A Percentage Of Build Chamber Height

By default, this is based on the default [Number of Parts for Laser Sintering](#). That is, by default, this is the fraction of the build chamber height that would have to be occupied by powder in order to accommodate the default number of parts.

You can override the default with this setup option. Specify a number between 0 and 1.

Powder height affects the number of part layers in the build chamber, cycle time, and material utilization.

Load and Splice Time

This option controls the time to load the part model into the machine software and splice it into layers. By default, the time is specified by the cost model variable **loadFileAndSpliceTime** (0.25 hours in starting point VPEs). Users can override the default with this option. See the formula for Amortized Batch Setup in [Setup Formula for Laser Sintering](#).

Base Powder Height

This option specifies the height of the powder layer that forms a buffer between the build platform and the bottom layer of parts. By default, this is specified by the site variable **basePlateOffset** (10mm in starting point VPEs). Users can override the default with this setup option. See [Machine Feasibility for Laser Sintering](#), [Cycle Time Formulas for Laser Sintering](#), [Number of Parts for Laser Sintering](#), and [Material Cost and Utilization for Laser Sintering](#).

Note: if you use the setup option to override the default base height, this does *not* affect how the base is displayed in the Viewer and does *not* affect the values of support structure geometric properties displayed in the Geometric Cost Drivers pane. The override *is* used, however, in the determination of machine feasibility, cycle time, number of parts, and material utilization.

Prepare Build Chamber Time

By default, the time per part to orient the part or parts on the build platform is specified by the cost model variable `slsPrepBuildChamber` (1200 seconds in starting point VPEs). Since the actual time may depend on how many parts are being built and how difficult they are to nest together, users can override the default on a part-by-part basis with this setup option. See [Cycle Time Formulas for Laser Sintering](#).

Heat Build Chamber Time

By default, the time per part to heat the build chamber is specified by the cost model variable `slsHeatChamberTime` (4140 seconds in starting point VPEs). Users can override the default on a part-by-part basis with this setup option. See [Cycle Time Formulas for Laser Sintering](#).

Cool Build Chamber Time

By default, the time per part to cool the build chamber after a sintering cycle is specified by the cost model variable `slsCoolChamberTime` (2180 seconds in starting point VPEs). Users can override the default on a part-by-part basis with this setup option. See [Cycle Time Formulas for Laser Sintering](#).

Powder Recycle Percentage

By default, the cost model assumes that a certain fraction of thermally damaged material is recovered, recycled, and added to material inventory for later use. The default fraction is specified by the material property `Recycle Percentage`. Users can specify a different value with this setup option. See [Material Cost and Utilization for Laser Sintering](#).

Number of Powder Cycles

This setup option controls the number of cycles after which all the material in the chamber is discarded. By default, this is specified by the material property `Max Powder Cycles`. Users can specify a different value with this setup option.

Metal Sintering Options

For the DMLS routing, you can specify the following process setup options:

- Layer Thickness
- Nesting Allowance
- Step Angle for True-Part Shape Nesting
- Number of Parts per Build Plate
- Base Plate: Support Structures Height
- Recoating Layer Speed Over
- Recoating Layer Speed Return
- Fitting Build Plate Time
- Load and Splice Time
- Inert Gas Purge Time
- Build Chamber Heat Time

- Build Chamber Cool Time

Layer Thickness

By default, the height of each layer to be sintered is halfway between the machine's minimum and maximum layer thickness (specified by the machine properties **Minimum Layer Thickness** and **Maximum Layer Thickness**). Users can override the default with the setup option. See the formula for Number of Layers in [Cycle Time Formulas for Metal Sintering](#).

Nesting Allowance

By default, the space allowance around nested parts is specified by the cost model variable **nestingAllowance** (5mm in starting point VPEs). Users can override the default nesting allowance with this setup option See [Number of Parts for Metal Sintering](#).

Step Angle for True-Part Shape Nesting

With true-part-shape nesting, the cost engine uses an internal algorithm that considers multiple candidate nesting arrangements using a variety of part orientations. By default, the various orientations differ by an angle specified by the cost model variable **defaultUtilizationStepAngle** (90° in starting point VPEs).

With this setup option, users can specify a step angle for the cost engine to use in order to generate additional candidate orientations—smaller nesting angles result in the consideration of a greater number of candidate nesting arrangements (which increases costing time, but may result in more efficient nesting).

Note that when the user specifies a step angle, the default candidate orientations are still included for consideration.

See [Number of Parts for Metal Sintering](#).

Number of Parts per Build Plate

By default, this is the maximum number of parts that can fit on the build platform, with a border around each part whose width is specified by the cost model variable **nestingAllowance** (5mm in starting point VPEs) or the setup option **Nesting Allowance**. With the setup option **Number of Parts**, users can override the default on a part-by-part basis, and specify a number of parts. See [Number of Parts for Metal Sintering](#).

Note that when you override the default with this setup option, the Material Nesting diagram can no longer be displayed.

Base Plate: Support Structures Height

This option specifies the height of the base support structure which forms a buffer between the build platform and the part. The default base height depends on the base-structure-removal process included in the current routing. The routing might include any of the processes listed below. Each base-removal process has an associated cost model variable that specifies the default base height for that process:

- Manual Tool Base Removal: **baseSupportHeightManualRemoval** (10mm in starting point VPEs).
- Power Tool Base Removal: **baseSupportHeightPowerRemoval** (10mm in starting point VPEs).

- Wire EDM (in the Machining process group): **baseSupportHeightWireEDM** (1mm in starting point VPEs).

Users can override the default base height with this setup option; such an override applies regardless of the base-structure-removal process in the current routing. See [Machine Feasibility for Metal Sintering](#), [Cycle Time Formulas for Metal Sintering](#), and [Material Cost Formulas for Metal Sintering](#).

Note: if you use the setup option to override the default base height, this does *not* affect how the base is displayed in the Viewer and does *not* affect the values of support structure geometric properties displayed in the Geometric Cost Drivers pane. The override *is* used, however, in the determination of machine feasibility, cycle time, and material utilization. See [Support Structures for Metal Sintering](#).

Recoating Layer Speed Over

This controls the speed at which the recoater blade travels across the machine bed to spread the powder. By default, it is specified by the cost model variable **dmlsPowderRecoatSpeedOver** (76mm/sec in starting point VPEs). Users can override the default with this setup option. See the formula for Recoat Time per Layer in [Cycle Time Formulas for Metal Sintering](#).

Recoating Layer Speed Return

This controls the speed at which the recoater blade returns to its starting point after spreading the powder. By default, it is specified by the cost model variable **dmlsPowderRecoatSpeedReturn** (200mm/sec in starting point VPEs). Users can override the default with the setup option. See the formula for Recoat Time per Layer in [Cycle Time Formulas for Metal Sintering](#).

Fitting Build Plate Time

By default, the time taken to fit and level the build plate in the machine bed is specified by the cost model variable **dmlsFitBuildPlateTime** (300 seconds in starting point VPEs). Users can override the default on a part-by-part basis with this setup option. See the formula for Preparation Time in [Cycle Time Formulas for Metal Sintering](#).

Load and Splice Time

This option controls the time to load the part model into the machine software and splice it into layers. By default, the time is specified by the cost model variable **loadFileAndSpliceTime** (0.25 hours in starting point VPEs). Users can override the default with this option. See the formula for Amortized Batch Setup in [Labor and Setup Formulas for Metal Sintering](#).

Inert Gas Purge Time

This controls the time taken to remove the oxygen from the build chamber prior to part construction. The default time is specified by the cost model variable **dmlsPurgeDuration** (1800 seconds in starting point VPEs). See the formula for Preparation Time in [Cycle Time Formulas for Metal Sintering](#).

Build Chamber Heat Time

By default, the time per part to heat the build chamber is specified by the cost model variable **dmlsHeatChamberTime** (3600 seconds in starting point VPEs). Users can override

the default on a part-by-part basis with this setup option. See [Cycle Time Formulas for Metal Sintering](#).

Build Chamber Cool Time

By default, the time per part to cool the build chamber after a sintering cycle is specified by the cost model variable **dmlsCoolChamberTime** (3600 seconds in starting point VPEs). Users can override the default on a part-by-part basis with this setup option. See [Cycle Time Formulas for Metal Sintering](#).

Resin Curing Options

For Resin Curing, you can specify the following process setup options:

- Layer Resolution
- Layer Thickness
- Nesting Allowance
- Step Angle for True-Part Shape Nesting
- Number of Parts per Build Plate
- Base Plate: Support Structures Height
- Preprocessing Time
- Load and Splice Time

Layer Resolution

By default, layer thickness is specified by the cost model variable **slaStandardLayerResolution** (0.1mm in starting point VPEs). With this setup option, users can override the default, and select high resolution (specified by the cost model variable **slaHighLayerResolution**—0.05mm in starting point VPEs). See [Cycle Time Formulas for Resin Curing](#).

Layer Thickness

By default, layer thickness is specified either by the cost model variable **slaStandardLayerResolution** (0.1mm in starting point VPEs) or the cost model variable **slaHighLayerResolution** (0.05mm in starting point VPEs), depending on the setting the option Layer Resolution (see below). With this option, users can override the default, and specify a thickness explicitly. See [Cycle Time Formulas for Resin Curing](#).

Nesting Allowance

By default, the space allowance around nested parts is specified by the cost model variable **nestingAllowance** (5mm in starting point VPEs). Users can override the default nesting allowance with this setup option See [Cycle Time Formulas for Resin Curing](#).

Step Angle for True-Part Shape Nesting

With true-part-shape nesting, the cost engine uses an internal algorithm that considers multiple candidate nesting arrangements using a variety of part orientations. By default, the various orientations differ by an angle specified by the cost model variable **defaultUtilizationStepAngle** (90° in starting point VPEs).

With this setup option, users can specify a step angle for the cost engine to use in order to generate additional candidate orientations—smaller nesting angles result in the consideration of a greater number of candidate nesting arrangements (which increases costing time, but may result in more efficient nesting).

Note that when the user specifies a step angle, the default candidate orientations are still included for consideration.

See [Number of Parts for Resin Curing](#).

Number of Parts per Build Plate

By default, this is the maximum number of parts that can fit on the build platform, with a border around each part whose width is specified by the cost model variable **nestingAllowance** (5mm in starting point VPEs) or the setup option [Nesting Allowance](#). With the setup option **Number of Parts**, users can override the default on a part-by-part basis, and specify a number of parts. See [Number of Parts for Resin Curing](#).

Note that when you override the default with this setup option, the Material Nesting diagram can no longer be displayed.

Base Plate: Support Structures Height

By default, this is specified by the site variable **basePlateOffset** (10mm in starting point VPEs). Users can override the default with this setup option. See [Machine Feasibility for Resin Curing](#), [Cycle Time Formulas for Resin Curing](#), and [Material Cost and Utilization for Resin Curing](#).

Note: if you use the setup option to override the default base height, this does *not* affect how the base is displayed in the Viewer and does *not* affect the values of support structure geometric properties displayed in the Geometric Cost Drivers pane. The override *is* used, however, in the determination of machine feasibility, cycle time, and material cost.

Preprocessing Time

By default, the time per part to orient the part or parts on the build platform is specified by the cost model variable **slaPreprocessingTime** (1200 seconds in starting point VPEs). Since the actual time may depend on how many parts are being built and how difficult they are to nest together, users can override the default on a part-by-part basis with this setup option. See [Cycle Time Formulas for Resin Curing](#).

Load and Splice Time

This option controls the time to load the part model into the machine software and splice it into layers. By default, the time is specified by the cost model variable **loadFileAndSpliceTime** (0.25 hours minutes in starting point VPEs). Users can override the default with this option. See the formula for Amortized Batch Setup in [Setup Formula for Resin Curing](#).

Part Curing Option

For Part Curing, you can specify [Number of Parts](#).

Number of Parts

By default, this is the maximum number of parts that can fit in the oven. The cost model assumes rectangular nesting, with a border around each part specified by the cost model variable **nestingAllowance** (5mm in starting point VPEs). With this setup option, users can override the default on a part-by-part basis, and specify a number of parts. See [Number of Parts for Part Curing](#).

Sieving Option

For Sieving, you can specify [Sieving Time per Run](#).

Sieving Time per Run

By default, this is specified by the cost model variable **powderSieveTimePerRun** (900 seconds in starting point VPEs). Users can override the default with this setup option. See [Sieving Formulas](#).

Powder Loading Option

For Powder Loading, you can specify [Powder Loading Time](#).

Powder Loading Time

By default, this is specified by the cost model variable **dmlsPowderLoadTime** (300 seconds in starting point VPEs). Users can override the default with this setup option. See [Powder Loading Formulas](#).

22 Heat Treatment Process Group

This chapter describes the costing details and inputs that are available for the Heat Treatment process group.

This chapter includes the following topics:

- Heat Treatment Overview
 - Heat Treatment Processes
 - Heat Treatment Machines
 - Heat Treatment Process Routings
 - Heat Treatment Process Setup
 - Heat Treatment Costing Details
-

Heat Treatment Overview

The Heat Treatment process group enables estimation of manufacturing times and costs for a variety of heat treatment processes and follow-on processes. If you have licensed the Heat Treatment module, Heat Treatment processes are available to be included in all other Process Group routings (with the exception of Plastic Molding) so that you can estimate the complete cost of manufacturing and finishing a part or assembly.

Heat Treatment Processes

The Heat Treatment process group includes multiple types of Heat Treatment processes and follow-on processes for both ferrous and non-ferrous materials:

- For Ferrous materials: Surface (Case) Hardening: Carburizing, Carbonitriding, Induction Hardening
- Through Hardening: Atmospheric Oil Hardening, Vacuum Air Hardening with/without High Temper, and material-specific hardening processes for spring steel, stainless steel, and high-speed steel
- Annealing: Standard, Low Temperature Vacuum, and High Temperature Vacuum
- Tempering processes: Standard Temper and Vacuum Temper, plus an Additional Temper process. Additional Temper is intended for use following an earlier process which includes tempering (e.g., Carburizing includes a tempering step, or if Standard or Vacuum Temper processes were employed previously).
- Age: for Bar & Tube parts that use extruded stock.
- For Non-Ferrous materials:
 - Solution Hardening
 - Aging (Precipitation Hardening)
 - Stress Relief
 - Cryogenic Freezing processes
- Follow-on Processes:
 - Straightening
 - Batch Certification
- Hot Isostatic Pressing

Heat Treatment Machines

By default, aPriori provides only one baseline machine for each Heat Treatment process, except Hot Isostatic Pressing. Therefore, this machine and its parameter values will be used to compute costs for the corresponding process.

Heat Treatment Process Routings

Heat Treatment is a secondary process group--these processes are applied in conjunction or subsequent to the primary manufacturing processes that are used to manufacture a part. As such, they are not available for selection when indicating the primary process group (for example, in the Production Info window or in the Select Primary Process Group window). Instead, you can Edit the process routing to include one or more Heat Treatment processes. All Heat Treatment processes are optional and by default they are not assigned automatically by aPriori, so you must include the processes of interest.

To include a Heat Treatment process in a routing (except for Plastic Molding routings)

- 1 In the Manufacturing Process pane, click the **Edit** menu and choose **Routing Selection...**
- 2 The Routing Selection window will appear. The second-to-last node of each routing is a Heat Treatment node (the last node is a Surface Treatment node). For the routing level of interest, **click the + symbol** to expand the Heat Treatment node into five nodes. The first node is an intermediate node called Heat Treat Processes and the next four nodes correspond to different types of follow-on processes (Straighten, Certification). **Click the + symbol** on the Heat Treat Processes node to expand it to nodes represent different categories of heat treatment processes (Surface/Case Hardening, Through Hardening, Annealing, Tempering, Solution Hardening, Aging/Precipitation Hardening, Stress Relief, and Cryogenic Freezing).
- 3 **Click the + symbols** on any of these category nodes to expand to the specific process(es) of interest. For example, expand the Surface Hardening node to show the Carburizing, Carbonitriding, and Induction Hardening processes.
- 4 To include a specific heat treatment or follow-on process in a routing, right-click on the process node and select **Include** from the popup menu. You can include multiple heat treatment and follow-on processes as appropriate (for example, you may wish to select Carburizing, Straightening, and Certification for a given part).

Note You must include the actual (lowest-level) process node. If you include only an intermediate node (such as Surface Hardening), aPriori does not automatically include the processes under it.

- 5 To remove a heat treatment or follow-on process from a routing, right-click on the process node and select **Exclude** or **Let aPriori Decide** from the popup menu.

Heat Treatment Process Setup

Some Heat Treatment processes allow you to provide additional inputs about the processes which can have an impact on cost estimates.

- **Masking** – For all the various Surface Hardening, Through Hardening, Annealing and primary Tempering processes, you can indicate the number of features to be

masked to prevent hardening of those features. The default is that No Masking is performed.

Note: the Masking option is not available for the Additional Temper process as it is assumed any masking will have been applied with earlier heat treatment processes.

- Carburizing Case Depth – for the Carburizing process, you can indicate the case depth range (either the standard depth range or a deeper range). The default behavior is to use the standard depth range, but if you choose the deeper range this will increase the Carburizing cost accordingly.

See also [Setup Options for Hot Isostatic Pressing](#).

Hot Isostatic Pressing

The Hot Isostatic Pressing process models densification of parts through the simultaneous use of both high temperature and high pressure. The pressure is applied equally to all surfaces of the part by an inert gas, which the cost model assumes to be Argon.

Each machine cycle has the following phases:

- Purge phase: air inside the vessel is replaced with the process gas.
- Pressurize phase: the vessel is pressurized to the hold pressure.
- Heating phase: temperature inside the temperature-controlled hot zone, within the vessel, is ramped up to the hold temperature.
- Hold phase: parts are held at high pressure and temperature within the hot zone for a period of time.
- Cool phase: the hot zone is cooled to ambient temperature.

This section covers the following topics:

- [Process Routing and Feasibility for Hot Isostatic Pressing](#)
- [Machine Selection for Hot Isostatic Pressing](#)
- [Formulas for Hot Isostatic Pressing](#)
- [Setup Options for Hot Isostatic Pressing](#)

Process Routing and Feasibility for Hot Isostatic Pressing

This process must be manually included in your routing.

Hot Isostatic pressing is not feasible for plastic materials; the current material must not have one of the following cut codes: 41, 42, 51, or 52.

Machine Selection for Hot Isostatic Pressing

aPriori selects the lowest-overhead machine whose hot zone dimensions can accommodate the part dimensions.

A machine's hot zone dimensions can accommodate the part dimensions if both the following hold:

- Machine property **Hot Zone Height** is no less than the part's longest dimension.
- Machine property **Hot Zone Diameter** is no less than the diagonal of the projection of the part bounding box along the longest dimension (that is, the diagonal of a face of the bounding box that is orthogonal to the longest side of the bounding box).

Overhead, here, is the given by the following:

$$\text{((Number of Batches * (Direct Overhead Rate + Indirect Overhead Rate)) / Production Volume)}$$

where

- Number of batches is the number of batches needed to achieve the production volume, given a batch size consisting of the maximum number of parts that can be accommodated by the machine (see below).
- Direct overhead rate is specified by a machine property.
- Indirect overhead rate is specified by a machine property.
- Production volume is specified in the Production Scenario tab of the Cost Guide.

The number of batches required for the current production volume is the result of rounding up the quotient of the production volume and the maximum number of parts that can be accommodated by the machine in one cycle:

$$\text{Number of Batches} = \text{roundup}(\text{Production Volume} / \text{Max Number of Parts})$$

The maximum number of parts is determined as described in [Number of Parts for Hot Isostatic Pressing](#).

Number of Parts for Hot Isostatic Pressing

The maximum number of parts that can be accommodated by the machine in a cycle is determined in one of two ways:

- *Part-projected-area method*: based on the dimensions of the part's bounding box (the GCD properties **Length**, **Width**, and **Height**)
- *Part-volume method*: based on the volume of the part (the GCD property **Volume**)

Part-projected-area method: By default in starting point VPEs, the maximum number of parts that can be accommodated by the machine is determined based on the following assumptions:

- Parts are oriented in the hot zone with the longest dimension running up and down.
- If the part's longest dimension is small enough relative to hot-zone height, there are multiple layers of parts.
- Parts have associated nesting allowances:
 - Minimum horizontal distance between parts is specified by the cost model variable **hipHorizontalNestingAllowance** (13mm in starting point VPEs).
 - Minimum vertical distance between parts is specified by the cost model variable **hipVerticalNestingAllowance** (10mm in starting point VPEs).
- Number of layers is the result of rounding down the quotient of the following:

- Hot zone height
- Part's longest dimension plus vertical nesting allowance
- Number of parts in each layer is the quotient of the following:
 - Area of the hot-zone floor, that is $(\text{Hot Zone Diameter}/2)^2\pi$
 - Area of the projection of the part's bounding box (augmented by horizontal nesting allowances) along its longest dimension (that is, the product of the shortest two part dimensions augmented by horizontal nesting allowances)

With this method, the maximum number of parts is the result of rounding down the product of the number of layers and the number of parts per layer:

Max Number of Parts =
 $\text{rounddown}(\text{Number of Layers} * \text{Number of Parts per Layer})$

This result is subject to the constraint that the volume of this number of parts does not exceed the available hot zone volume (see below). If this constraint is not satisfied, the Part-volume method is used.

Part-volume method: Alternatively, the maximum number of parts is the result of rounding down the quotient of the following quantities:

- Volume of the hot zone that can be occupied by parts (the remainder must be occupied by the process gas)
- Part volume

Max Number of Parts =
 $\text{rounddown}(\text{Max Fraction Occupied by Parts} * \text{Hot Zone Volume} / \text{Part Volume})$

The maximum fraction of the hot zone that can be occupied by parts is specified by the cost model variable `hipMaxPercentageSolidVolumeFromHotZoneVolume` (0.6 in starting point VPEs).

By default in starting point VPEs, the part-projected-area method is used. Administrators can customize the default with the cost model variable `defaultPartLoadingMethod` (set to **Part Projected Area** or **Part Volume**). Users can override the default on a part-by-part basis with the setup option `Part Loading Method`.

Formulas for Hot Isostatic Pressing

This section covers the following topics:

- Labor and Setup Costs for Hot Isostatic Pressing
- Cycle Time Formulas for Hot Isostatic Pressing
- Process Gas Cost for Hot Isostatic Pressing
- Yield Formulas for Hot Isostatic Pressing

Labor and Setup Costs for Hot Isostatic Pressing

Labor and setup costs are given by the following formulas:

Labor Cost = Labor Time * Labor Rate / Final Yield

Labor cost depends on the following:

- Labor time (see formula below)

- Labor rate (specified as a machine property)
- Final yield (see [Yield Formulas for Hot Isostatic Pressing](#))

Labor Time =
(Cycle Time * Number of Operators * Labor Time Standard) +
Labor Handling Time

Labor time depends on the following:

- Cycle time (see [Cycle Time Formulas for Hot Isostatic Pressing](#))
- Number of operators (specified as a machine property)
- Labor time standard: specified as the machine property **Labor Time Standard**. This multiplier is used to account for otherwise unaccounted for factors that affect labor time, such as operator fatigue or time spent by the operator for cleaning or maintenance.
- Labor handling time (see formula)

Labor Handling Time =
(Load Time + Unload Time) * Number of Handling Operators * Labor Time
Standard

This is the labor time required to rack or wire up one part to be placed in the heat treatment furnace:

- Load time: time to rack or wire up one part to be placed in the heat treatment furnace. This time is interpolated from values looked up by mass in the lookup table **tblHandlingTimes**. The interpolated value is based on the table rows whose **Max Weight** values straddle the mass that must be handled. If the mass falls below the minimum mass listed in the table, the handling time is considered negligible, and is set to 0. If the mass exceeds the maximum mass listed in the table, aPriori uses the values in the row with the maximum mass.
- Unload time: time to remove a part from the heat treatment furnace. This is assumed to be the same as load time (see above).
- Number of handling operators: number of operators loading and unloading parts. By default in starting point VPEs, this is looked up by mass in the lookup table **tblHandlingTimes**. Users can override the default on a part-by-part basis with the setup option [Labor Handling Number of Operators](#).
- Labor time standard: specified as the machine property **Labor Time Standard**. This multiplier is used to account for otherwise unaccounted for factors that affect labor time, such as operator fatigue or time spent by the operator for cleaning or maintenance.

Amortized Batch Setup =
(Setup Time * (Labor Rate + Direct Overhead Rate)) / Batch Size

Batch setup cost per part depends on the following:

- Setup time (specified by the cost model variable **hipProgrammingTime**—0.25 hours in starting point VPEs)
- Labor rate (specified by the machine property **Labor Rate**)
- Direct overhead rate (see [Direct and Indirect Overhead](#))
- Batch size (specified in the **Production Scenario** screen of the Cost Guide)

Cycle Time Formulas for Hot Isostatic Pressing

The calculation of cycle time relies on the formulas below.

Cycle Time = Process Time * Cycle Time Adjustment Factor

Cycle time is the product of the following:

- Process time (see formula)
- Cycle Time Adjustment Factor: value of the cost model variable **cycleTimeAdjustmentFactor**. This is set to 1 in aPiori starting point VPEs. VPE administrators can change the cost model variable to globally adjust cycle times.

Process Time = (Vacuum Purge and Equalize Time + Pressurize System Time + Heat Time + Holding Time + Cool Time) / Number of Parts

Process time per part depends on the following:

- Vacuum purge and equalize time: time to fill the vessel with the inert, process gas, and equalize vessel pressure with the pressure in the gas inlet lines. By default, this is specified by the cost model variable **vacuumPurgeEqualize** (9 minutes in starting point VPEs). You can override the default on a part-by-part basis with the setup option [Vacuum Purge and Equalize Pressure](#).
- Pressurize system time: time to bring the vessel to the required hold pressure. By default, this is specified by the cost model variable **pressurizingVesselTime** (40 minutes in starting point VPEs). You can override the default on a part-by-part basis with the setup option [Pressurize Vessel Time](#).
- Heat time: by default, heat time is given by the formula for Default Heating Time, below. Users can override the default on a part-by-part basis with the setup option [Heating Time](#).
- Holding time: by default, this is looked up by material type in the lookup table **tblMaterialTypeProperties**. If the material type is not found, default holding time is given by the cost model variable **averageHoldTime** (2.6 hours in starting point VPEs). Users can override the default on a part-by-part basis with the setup option [Hold Time](#).
- Cool time: by default, cool time is given by the formula for Default Cooling Time, below. Users can override the default on a part-by-part basis with the setup option [Cooling Time](#).
- Number of parts: number of parts per batch--see [Number of Parts for Hot Isostatic Pressing](#).

Default Heating Time = (Material Hold Temperature – Room Temperature) / Heating Rate

Default heating time depends on the following:

- Material hold temperature: looked up by material type in the lookup table **tblMaterialTypeProperties**. Specified in degrees Celsius.
- Room temperature: specified by the cost model variable **defaultRoomTemperature** (15°C in starting point VPEs).

- Heating rate: by default, this is looked up by material type in the lookup table **tblMaterialTypeProperties**. If the material type is not found, default heating rate is given by the cost model variable **averageHeatingRate** (7.2°C per minute, in starting point VPEs). Users can override the default on a part-by-part basis with the setup option [Heating Rate](#).

Default Cooling Time =
(Material Hold Temperature – Room Temperature) / Cooling Rate

Default heating time depends on the following:

- Material hold temperature: looked up by material type in the lookup table **tblMaterialTypeProperties**.
- Room temperature: specified by the cost model variable **defaultRoomTemperature** (15°C in starting point VPEs).
- Cooling rate: by default, this is looked up by material type in the lookup table **tblMaterialTypeProperties**. If the material type is not found, default cooling rate is given by the cost model variable **averageCoolingRate** (13.3°C per minute, in starting point VPEs). Users can override the default on a part-by-part basis with the setup option [Cool Rate](#).

Process Gas Cost for Hot Isostatic Pressing

The cost for the process gas is accounted for in Additional Direct Costs:

Additional Direct Costs = Actual Gas Cost Per Part / Final Yield

This is the per-part cost for process gas, taking into account process yield. It depends on the following:

- Actual gas cost per part (see formula)
- Final yield (see [Yield Formulas for Hot Isostatic Pressing](#)).

Actual Gas Cost Per Part = Actual Gas Cost / Number of Parts

This is the per-part cost of process gas. It depends on the following:

- Actual gas cost (see formula)
- Number of parts: number of parts processed per machine cycle. See [Number of Parts for Hot Isostatic Pressing](#).

Actual Gas Cost = Hot Zone Gas Cost * (1 – Gas Reuse Percentage)

Cost of the process gas used for one machine cycle (that is, for one batch of parts), taking into account gas recycling. It depends on the following:

- Hot zone gas cost (see formula)
- Gas reuse percentage: this is the fraction of gas from one machine cycle that is recycled and used in the next machine cycle. By default in starting point VPEs, this is 0.95 (that is, 95% of the gas is reused). Administrators can customize the default with the cost model variable **hipDefaultGasReusePercentage**. Users can override the default on a part-by-part bases with the setup option [Gas Reuse Percentage](#).

Hot Zone Gas Cost = Required Gas Volume * Argon Gas Cost Per Cubic Meter

Cost of the process gas used for one machine cycle. This does *not* take into account gas recycling, but rather reflects what the cost would be in the absence of recycling. It is the product of the following:

- Required gas volume (see formula)
- Argon gas per cubic meter (specified by the machine property **Argon Gas Cost**)

$$\text{Required Gas Volume} = \frac{\text{Net Gas Volume In Hot Zone}}{(\text{Machine Hold Pressure} / \text{Gas Cylinder Pressure}) * (\text{Gas Cylinder Temperature} / \text{Machine Hold Temperature})}$$

This formula is an application of the combined gas law. During the hold phase of a machine cycle (when parts are held for a period of time at high pressure and temperature), the portion of the hot zone that is not occupied by parts is filled with the process gas (assumed to be Argon). A certain number, n , of molecules of process gas is required to fill this space at hold pressure and temperature. Required Gas Volume is the volume of this number, n , of molecules of process gas at standard pressure and ambient temperature (or whatever is the pressure and temperature inside the gas cylinder from which the process gas is fed into the vessel). Required Gas Volume depends on the following:

- Net gas volume in hot zone: volume of gas in the hot zone at hold pressure and temperature. See formula.
- Machine hold pressure: pressure in the hot zone during the hold phase of the machine cycle. By default in starting point VPEs, this is 100 MPa. Administrators can customize the default with the cost model variable **hipDefaultHoldPressure**. Users can override the default on a part-by-part basis with the setup option **Hold Pressure**.
- Gas cylinder pressure: pressure inside the gas cylinder from which the process gas is fed into the vessel. This is specified by the cost model variable **hipGasCylinderPressure** (in starting point VPEs, this is standard pressure, 0.101325 MPa).
- Gas cylinder temperature: temperature inside the gas cylinder from which the process gas is fed into the vessel (which presumably is the ambient temperature). This is specified in degrees Celsius by the cost model variable **defaultRoomTemperature** (15 degrees Celsius in starting point VPEs), and is converted to Kelvin for this calculation.
- Machine hold temperature: temperature of the hot zone during the hold phase of the machine cycle. This temperature is material-specific, and is looked up by material type in the lookup table **tblMaterialTypeProperties** (converted to Kelvin for this calculation).

$$\text{Net Gas Volume In Hot Zone} = \text{Machine Hot Zone Volume} - \text{Total Loaded Parts Volume}$$

This is the volume of the portion of the hot zone that is not occupied by parts. It is the difference between the following volumes:

- Machine hot zone volume: the hot zone is assumed to be cylindrical with diameter specified by the machine property **Hot Zone Diameter** and height specified by the machine property **Hot Zone Height**.

- Total loaded parts volume: this is the volume of the portion of the hot zone that is occupied by parts. It is the product of the GCD property **Volume** and the number of parts per machine batch (see [Number of Parts for Hot Isostatic Pressing](#)).

Yield Formulas for Hot Isostatic Pressing

Yields are calculated with the formulas below.

Final Yield = Final Output Volume / Local Input Volume

Final yield affects material, labor, and overhead costs per part. It is the fraction of parts created by this process in the current production scenario that will survive as good parts once any secondary processes are completed. That is, final yield is the fraction of parts created by this process that are *not* discarded as scrap parts, either by this process or by a downstream process. Final yield depends on the following:

- Final output volume is the number of parts created by this process that are *not* discarded as scrap parts, either by this process or by a downstream process. It is the product of the annual volume and number of production years, specified in the Production Scenario screen of the Cost Guide.
- Local Input volume (see the formula below). This is the total number of parts produced by this process, including all parts discarded as scrap from this process or downstream processes.

Local Input Volume = Local Output Volume + Number of Scrap Parts for This Process

Local input volume is the total number of parts produced by this process in the current scenario, including all parts discarded as scrap from this process or downstream processes. It is the sum of the following:

- Local output volume (see the formula below). This is the number of parts produced by this process, excluding parts discarded as scrap by this process, but including parts that are discarded as scrap by downstream processes.
- Number of scrap parts for this process (see the formula below)

Local Output Volume = Final Output Volume + Number of Scrap Parts Downstream

Local output volume is the number of parts produced by this process in the current scenario, excluding parts discarded as scrap by this process, but including parts that are discarded as scrap by downstream processes. It is the sum of the following:

- Final output volume is the number of parts created by this process that are *not* discarded as scrap parts, either by this process or by a downstream process. It is the product of the annual volume and number of production years, specified in the Production Scenario screen of the Cost Guide
- Number of Scrap Parts Downstream. This the number of parts discarded as scrap by downstream processes.

Number of Scrap Parts for This Process = (Local Output Volume / Local Good Part Yield) – Local Output Volume

Number of scrap parts for this process is the number of parts produced by this process in the current scenario that are discarded as scrap by this process, before any downstream process is performed on them. It is a function of the following:

- Local output volume (see the formula above). This is the number of parts produced by this process, excluding parts discarded as scrap by this process, but including parts that are discarded as scrap by downstream processes.

- Local good part yield (specified by the machine property **Good Part Yield**). This is the fraction of parts produced by this process that are not discarded as scrap by this process but may be discarded as scrap by downstream processes.

Setup Options for Hot Isostatic Pressing

This process provides the following setup options:

- Part Loading Method
- Number of Parts
- Vacuum Purge and Equalize Pressure
- Pressurize Vessel Time
- Heating Rate
- Heating Time
- Hold Pressure
- Hold Time
- Cool Rate
- Cooling Time
- Labor Handling Number of Operators
- Gas Reuse Percentage

Part Loading Method

Determines how aPiori calculates the number of parts per machine batch, that is, the number of parts processed in one machine cycle. The default method is specified by the cost model variable **defaultPartLoadingMethod** (**Part Projected Area** in starting point VPEs). Users can override the default with this setup option. Choose one of the following:

- **Part Projected Area**: based on the dimensions of the part's bounding box (the GCD properties **Length**, **Width**, and **Height**)
- **Part Volume**: based on the volume of the part (the GCD property **Volume**)

See [Number of Parts for Hot Isostatic Pressing](#) for detailed information.

Number of Parts

Specifies the number of parts per machine batch, that is, the number of parts processed in one machine cycle. By default this is determined as described in [Number of Parts for Hot Isostatic Pressing](#). You can override the default with this setup option.

Vacuum Purge and Equalize Pressure

Specifies the time (in minutes) to fill the vessel with the inert, process gas, and equalize vessel pressure with the pressure in the gas inlet lines (see [Cycle Time Formulas for Hot Isostatic Pressing](#)). By default, this is specified by the cost model variable **vacuumPurgeEqualize** (9 minutes in starting point VPEs). You can override the default with this setup option.

Pressurize Vessel Time

Specifies the time (in minutes) required to bring the vessel to the required hold pressure (see [Cycle Time Formulas for Hot Isostatic Pressing](#)). By default, this is specified by the cost model variable **pressurizingVesselTime** (40 minutes in starting point VPEs). You can override the default with this setup option.

Heating Rate

Specifies the rate (in degrees Celsius per minute) at which the temperature in the hot zone is ramped up to the hold temperature (see [Cycle Time Formulas for Hot Isostatic Pressing](#)). By default, this is looked up by material type in the lookup table **tblMaterialTypeProperties**. If the material type is not found, default heating rate is given by the cost model variable **averageHeatingRate** (7.2°C per minute, in starting point VPEs). You can override the default with this setup option.

Heating Time

Specifies the time (in hours) required to ramp up the temperature in the hot zone to the hold temperature (see [Cycle Time Formulas for Hot Isostatic Pressing](#)). By default, this is based on the heating rate and the difference between the ambient temperature and the hold temperature. You can override the default with this setup option.

Hold Pressure

Specifies the pressure (in MPa) in the hot zone during the hold phase of the machine cycle. This is used to calculate gas cost—see [Process Gas Cost for Hot Isostatic Pressing](#). By default, this is specified by the cost model variable **hipDefaultHoldPressure** (100 MPa in starting point VPEs). You can override the default with this setup option.

Hold Time

Specifies the duration (in hours) of the hold phase of the machine cycle, during which parts are held at high pressure and temperature (see [Cycle Time Formulas for Hot Isostatic Pressing](#)). By default, this is looked up by material type in the lookup table **tblMaterialTypeProperties**. If the material type is not found, default hold time is given by the cost model variable **averageHoldTime** (2.6 hours in starting point VPEs). Users can override the default with this setup option.

Cool Rate

Specifies the rate (in degrees Celsius per minute) at which the hot zone is cooled down from the hold temperature to the ambient temperature (see [Cycle Time Formulas for Hot Isostatic Pressing](#)). By default, this is looked up by material type in the lookup table **tblMaterialTypeProperties**. If the material type is not found, default cooling rate is given by the cost model variable **averageCoolingRate** (13.3°C per minute, in starting point VPEs). You can override the default with this setup option.

Cooling Time

Specifies the time (in hours) required to cool down the hot zone from the hold temperature to the ambient temperature (see [Cycle Time Formulas for Hot Isostatic Pressing](#)). By default, this is based on the cool rate and the difference between the ambient temperature and the hold temperature. You can override the default with this setup option.

Labor Handling Number of Operators

Specifies the number of operators racking or wiring up parts to be placed in the heat treatment furnace (see [Labor and Setup Costs for Hot Isostatic Pressing](#)). By default, this is looked up by weight in the lookup table **tblHandlingTimes**. You can override the default with the setup option

Gas Reuse Percentage

Specifies the fraction of gas from one machine cycle that is recycled and used in the next machine cycle. This is used to calculate gas cost—see [Process Gas Cost for Hot Isostatic Pressing](#). By default, this is specified by the cost model variable **hipDefaultGasReusePercentage** (in starting point VPEs this is 0.95--that is, 95% of the gas is reused). You can override the default with the setup option.

Heat Treatment Costing Details for Other Processes

The Heat Treatment process group uses the following costing rules:

- If a heat treatment or follow-on process is Included in a primary process group routing, then the costs associated with that process are computed by the Heat Treatment cost model and combined with the primary process group costs to produce a total manufacturing process cost.
- Costs associated with heat treatment processes are reported in two places in the cost taxonomy: labor costs related to masking and racking part are output in the Labor cost field, and costs related to the heat treatment (furnace) costs are reported in the Additional Direct Costs fields.



23 Surface Treatment Process Group

This chapter describes the costing details and inputs that are available for the Surface Treatment process group.

This chapter includes the following topics:

- Surface Treatment Cost Model Overview
 - Surface Treatment Feasibility and Routing
 - Cost Algorithms and Calculations
 - User Inputs
 - Process Defaults and Thresholds
-

Surface Treatment Cost Model Overview

The Surface Treatment process group enables estimation of manufacturing costs for a variety of cleaning and finishing processes. If you have licensed the Surface Treatment module, Surface Treatment processes are available to be included in all other Process Group routings, so that you can estimate the complete cost of manufacturing and finishing a part or assembly.

The default Surface Treatment processes available in aPriori include:

- Shot Blast
- Shot Peen
- Degreasing
- Wet Coat Line painting
- Powder Coat Cart painting
- Painting
- Electroplating (Decorative Chrome, Hard Chrome, Nickel, Zinc)
- Screen Printing
- Passivation
- Mask Spray (for use with chemical milling—see [Chemical Milling](#))
- Mask Bench
- Anodize
- Vibratory Finishing (models tumble deburr)

For some surface treatment processes (for example, Wet Coat Line), each machine represents a workcenter configuration that can include options such as number of operators staffing the line and paint type/unit cost. You should determine which machine best represents the actual manufacturing environment relevant to the part.

For most Surface Treatment processes, aPriori auto-selects the default machine (see [Surface Treatment Machine Selection](#) for exceptions). If you feel another machine better represents the actual manufacturing environment, you can manually select a different machine using the Edit Machine Selection window which lists the properties of all machines available at the facility.

Surface Treatment Feasibility and Routing

This section contains the following subsections:

- [Surface Treatment Routing](#)
- [Surface Treatment Feasibility](#)

Surface Treatment Routing

Surface Treatment is a secondary process group--its processes are applied in conjunction with or subsequent to the primary manufacturing processes that are used to manufacture a part. As such, they are not available for selection when indicating the primary process group (for example, in the Production Info window or in the Select Primary Process Group window). Instead, you can edit the process routing to include one or more Surface Treatment processes. All Surface Treatment processes are optional and by default they are not assigned automatically by aPiori, so you must explicitly include the processes of interest.

Follow these steps to include a Surface Treatment process in a routing:

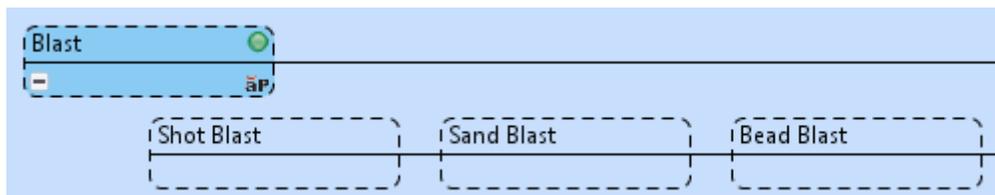
- 1 In the Manufacturing Process pane, click the **Edit** menu and choose **Routing Selection...**
- 2 The Routing Selection window will appear. The last node of each routing is a Surface Treatment node. For the routing level of interest, click the **+** symbol to expand the Surface Treatment node into four intermediate nodes representing different types of Surface Treatment (Shot Blast, Painting Processes, Electroplating, and Labelling).
- 3 **Click the + symbol** on each intermediate node to expand it into distinct surface treatment processes. For example, the Painting Processes node expands into three distinct painting processes: a Wet Coat Line, a Powder Coat cart-based process, and a generalized Painting process that can be used to represent any painting process based on cost per surface area.
- 4 To include a specific surface treatment process in a routing, right-click on the process node and select **Include** from the popup menu. You can include multiple surface treatment processes as appropriate (for example, you may wish to select both Painting and Screen Printing for a given part).

Note You must include the lowest-level process node or component-level operation node. If you include only an intermediate node (such as Painting Processes), aPiori does not automatically include the processes under it.

- 5 To remove a surface treatment process from a routing, right-click on the process node and select **Exclude** or **Let aPiori Decide** from the popup menu.

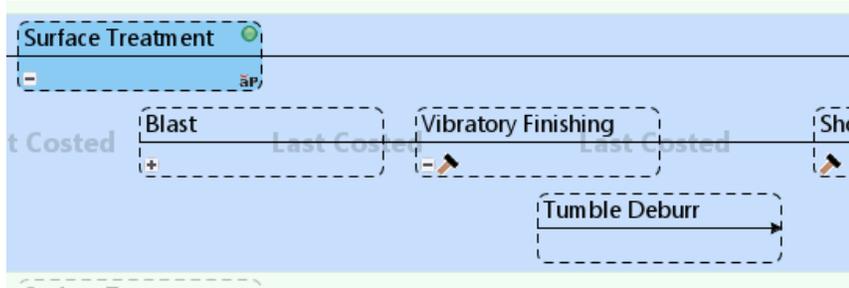
Surface treatment processes include the following:

- Blast processes:

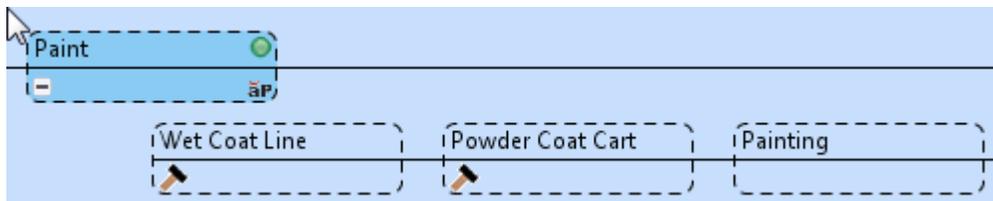


- Shot Peen process
- Degrease process
- Mask-Bench process
- Anodize process (see [Anodize Routing](#))

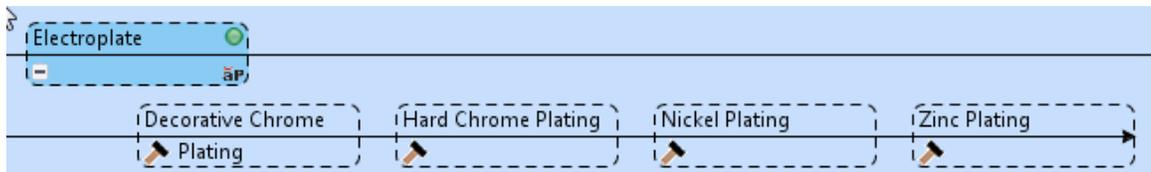
- Vibratory Finishing process (models tumble deburr; surface finishing to be added in a future release)



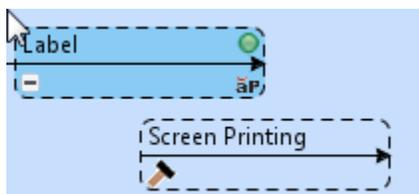
- Manual Paint: models the application of a specified number of coats of primer and a specified number of finish coats. Each primer or finish coat is preceded by hand sanding and hand cleaning, and is followed by curing. Any holes are masked by the Mask-Bench process. See also [Manual Paint Inputs](#).
- Paint processes:



- Electroplate processes:



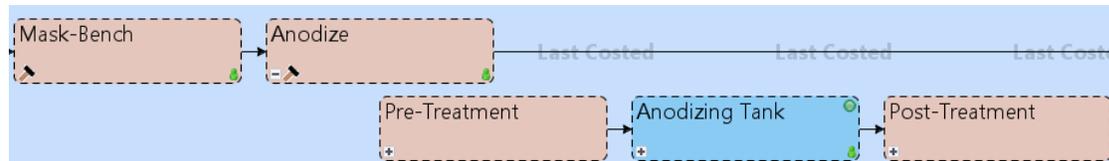
- Label process:



- Passivation process

Anodize Routing

Anodizing is an electrochemical process that converts the metal surface of a part into a decorative, durable, corrosion-resistant, anodic oxide finish. aPiori's anodizing cost model supports aluminum parts, and uses one process, Anodize, which has several component-level child operations. The child operations are divided into three groups: Pre-treatment operations, Anodizing operations, and Post-treatment operations:



The pre-treatment operations include the following:

- Clean: removes any grease or dirt from the surface.
- Etch: removes some of the aluminum material from the top surface.
- Deoxidize: removes surface oxides.
- Rinse: the part is rinsed multiple times during pre-treatment.

The Anodizing operations include the following:

- One of the following:
 - Anodize Type I: chromic acid anodizing
 - Anodize Type IB: low voltage, chromic acid anodizing
 - Anodize Type IC: non-chromic anodizing
 - Anodize Type II: sulfuric acid anodizing
 - Anodize Type III: hard anodic coatings (possibly sulfuric acid)

This is the main stage of the process, during which the part is dipped in the acid bath to form the oxide film.

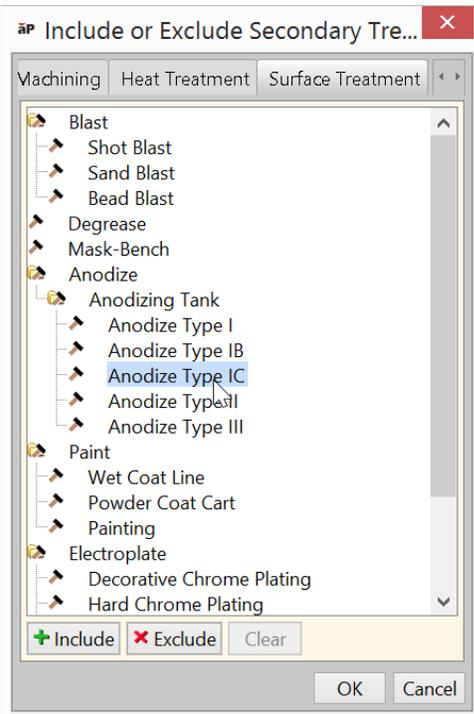
Note that type IIB anodizing is also supported—see below.

- Rinse
- Spray Rinse

The post-treatment operations include the following:

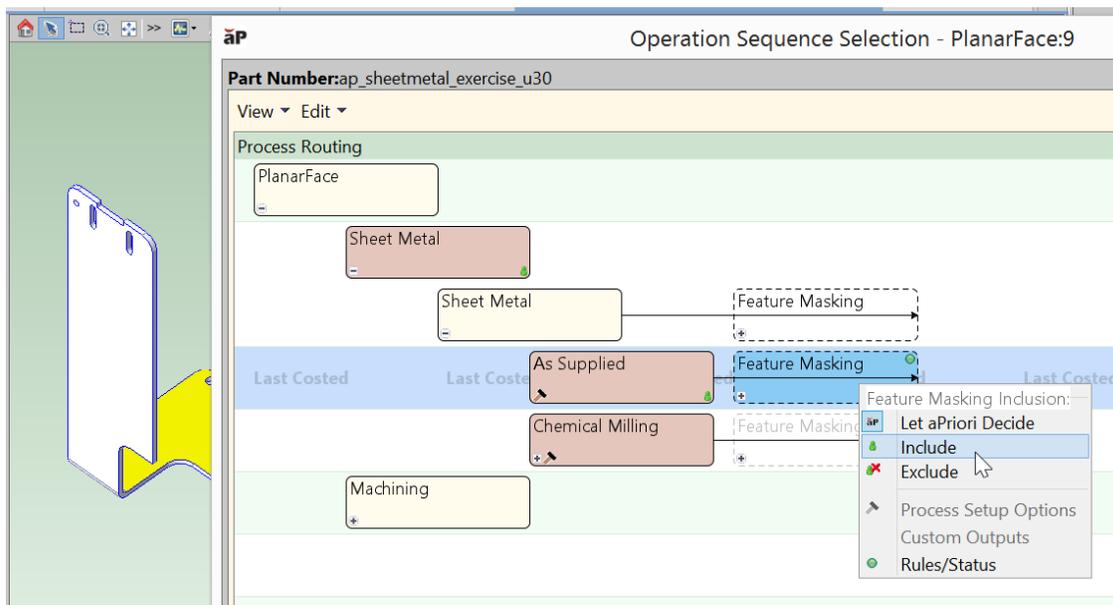
- Seal (optional): closes the pores on the part. This is included by default, but users can override the default on a part-by-part basis with the setup option [Enable Sealing Operation](#). Typically, if parts are painted, they are not sealed.
- Dry

When you add Anodizing to your routing, be sure to specify which Anodizing operation you want to include:



To estimate the cost of type IIB anodizing, select **Anodize Type II**, and use the setup option **Specify Anodize Coating Thickness** to set the layer thickness to the desired value, which typically is between 0.00635mm and 0.01016mm (0.0004 inch and 0.00025 inch).

Anodizing is optionally preceded by the Mask-Bench process, in order to model the process of masking portions of the part that should not be anodized. If you want to model any masking, manually include the Mask-Bench process in your routing. Once the process is included, you can manually assign individual features to the Masking operation:



In addition, threaded holes and threaded curved walls are automatically assigned feature masking.

Surface Treatment Feasibility

This section contains the following subsections:

- Shot Blast Feasibility
- Shot Peen Feasibility
- Powder Coat Cart Feasibility
- Plating Process Feasibility
- Degrease Feasibility
- Anodize Feasibility
- Vibratory Finishing Feasibility

Other surface treatment processes have no feasibility requirements.

Shot Blast Feasibility

This process is feasible only if the cut code family for the part material is *not* one of the following:

- 41
- 42
- 51
- 52

Shot Peen Feasibility

This process is feasible only if the cut code family for the part material is *not* one of the following:

- 33 (Copper)
- 41 (Thermoplastics)
- 42 (Thermosetting Plastics)
- 51 (Thermosetting Plastics)
- 52 (Thermosetting Plastics)

Powder Coat Cart Feasibility

This process is feasible only if the cut code family for the part material is *not* one of the following:

- 41 (Thermoplastics)
- 42 (Thermosetting Plastics)
- 51 (Thermosetting Plastics)
- 52 (Thermosetting Plastics)

Plating Process Feasibility

This process is feasible only if the part material is *not* one of the following:

- PVC
- PBT
- Polyethylene

Degrease Feasibility

This process is feasible only if part dimensions are all non-null and non-zero.

This process is feasible only if the cut code family for the part material is *not* one of the following:

- 41 (Thermoplastics)
- 42 (Thermosetting Plastics)
- 51 (Thermosetting Plastics)
- 52 (Thermosetting Plastics)

Passivation Feasibility

Passivation can only be performed on stainless steel materials; the material's cut code must appear in the global lookup table **passivationTreatments**.

Bench Mask Feasibility

Bench mask operations apply only to the following:

- Features that have been manually assigned to the Masking-Bench operation
- Threaded features (Simple Holes or Curved Walls) of a part that has been routed to Anodizing.

Anodize Feasibility

Anodizing can only be performed on aluminum.

Vibratory Finishing Feasibility

This process is not available for assemblies.

Surface Treatment Machine Selection

This section has the following subsections:

- Shot Peen Machine Selection
- Manual Paint Machine Selection
- Powder Coat Cart Machine Selection
- Wet Coat Line Machine Selection
- Degrease Machine Selection
- Mask Spray Machine Selection
- Mask Bench Machine Selection
- Anodize Machine Selection
- Vibratory Finishing Machine Selection

Other surface treatment processes always select the default machine.

Shot Peen Machine Selection

Shot Peen selects the default machine, if there is one. Otherwise, it selects the lowest-overhead machine, that is, the machine with the lowest overhead rate, given by the sum of the machine properties **Direct Overhead Rate** and **Indirect Overhead rate**.

Manual Paint Machine Selection

Manual Paint selects the lowest-overhead machine (paint booth) that can accommodate the part dimensions.

Powder Coat Cart Machine Selection

aPriori selects the default machine if it is feasible; otherwise, aPriori selects the feasible machine with the lowest overhead (specified by the sum of the machine properties **Direct Overhead Rate** and **Indirect Overhead Rate**). The machine feasibility rules require that all the following hold:

- Part dimensions can be accommodated by machine window, as specified by the machine properties **Cart Window Length** and **Cart Window Height**.
- Part weight (the product of part volume and material density) does not exceed the machine property **Cart Weight Limit**.

Wet Coat Line Machine Selection

aPriori selects the default machine if it is feasible; otherwise, aPriori selects the feasible machine with the lowest overhead (specified by the sum of the machine properties **Direct Overhead Rate** and **Indirect Overhead Rate**). The machine feasibility rules require that all the following hold:

- Part dimensions can be accommodated by machine window, as specified by the machine properties **Loadbar Window Length** and **Loadbar Window Height**.
- Part weight (the product of part volume and material density) does not exceed the machine property **Loadbar Weight Limit**.

Degrease Machine Selection

aPriori selects the default machine if it is feasible; otherwise, aPriori selects the feasible machine with the lowest overhead (specified by the sum of the machine properties **Direct Overhead Rate** and **Indirect Overhead Rate**). The machine feasibility rules require that all the following hold:

- Size constraint: If the user specifies the number of parts at a time to fit through the conveyor entrance (see the PSO [Number of parts that can fit across conveyor entrance](#)), the parts can be accommodated by the entrance dimensions, as specified by the machine properties **Conveyor Window Height**, **Conveyor Window Width** and **Conveyor Spacing Factor**. (The spacing factor is the fraction of tightly packed parts that can fit when parts are spaced appropriately.) This assumes that the part's longest dimension is aligned with the length of the conveyor belt, and the two shorter dimensions are aligned with the entrance's width and height (whichever height/width alignment maximizes the number of parts that can fit in the entrance).
- Size constraint: If the user does not specify the number of parts at a time to fit through the conveyor entrance (see the PSO [Number of parts that can fit across conveyor entrance](#)), at least one part can be accommodated by the entrance dimensions (see previous constraint).
- Weight constraint: If the user specifies the number of parts at a time to fit through the conveyor entrance (see the PSO [Number of parts that can fit across conveyor entrance](#)), weight of all parts in a window does not exceed the machine property **Conveyor Weight Limit**. Part weight is the product of part volume and material density. The number of parts in a window is the product of the following:

- Number of parts in entrance (see the first constraint above)
- Number of parts in a single row (machine property **Conveyor Window Length** divided by the part's longest dimension)
- Weight constraint: If the user does not specify the number of parts at a time to fit through the conveyor entrance (see the PSO [Number of parts that can fit across conveyor entrance](#)), weight of at least one row of parts does not exceed the machine property **Conveyor Weight Limit**. Part weight is the product of part volume and material density. The number of parts in one row is the machine property **Conveyor Window Length** divided by the part's longest dimension.
- Speed constraint: Calculated or user-specified conveyor speed (see the PSO [Speed of conveyor](#)) does not exceed the machine property **Conveyor Speed Limit**. Calculated speed is the fraction of **Conveyor Speed Limit** specified by the cost model variable **conveyorSpeedRateRatio** (0.1 | aPriori starting point VPEs).

Passivation Machine Selection

aPriori selects the default machine if it is feasible; otherwise, aPriori selects the feasible machine with the lowest overhead (specified by the sum of the machine properties **Direct Overhead Rate** and **Indirect Overhead Rate**). The machine feasibility rules require that the part dimensions can be accommodated by the machine working zone, as specified by the machine properties **Machine Window Length** and **Machine Window Width**.

Mask Spray Machine Selection

aPriori selects the feasible machine with the lowest power (specified by the property **Machine Power**). The machine feasibility rules require that the part dimensions can be accommodated by the dimensions of the paint booth (specified by the machine properties **Usable Length**, **Usable Width**, and **Usable Height**).

The cost model assumes that the part is on its side, that is, with its width oriented along the height of the booth. So part width must be no greater than booth height, part height must be no greater than booth width (sometimes referred to as “depth”), and part length must be no greater than booth length.

Mask Bench Machine Selection

For the Mask Bench process, aPriori selects the default machine, which represents the work area in which individual features are masked.

Anodize Machine Selection

aPriori selects the feasible machine with the lowest estimated cost per part, given the annual production volume of the current scenario.

The machine feasibility rules require the following:

- The machine property **Anodizing Type** specifies the type of anodizing in the current routing. The following types are supported:
 - **Anodizing Type I**
 - **Anodizing Type IB**
 - **Anodizing Type IC**
 - **Anodizing Type II**
 - **Anodizing Type III**

Note that **Anodize Type II** machines support both type II anodizing and type IIB anodizing—see [Anodize Routing](#).

- Part length is no greater than the machine property **Loadbar Window Length**.
- Part's shortest dimension (width or height, whichever is smaller) is no greater than the machine property **Loadbar Window Width**.
- Part's middle dimension (width or height, whichever is greater) is no greater than the machine property **Loadbar Window Height**.
- Part surface area is no greater than the machine property **Loadbar Max Load Surface Area**.

Cost per part is estimated with the following formula:

$$\text{Cost Per Part} = \frac{(\text{Minimum Batch Cost} * \text{Number Of Load Bars}) + (\text{Total Overhead Rate} * \text{Number Of Load Bars})}{\text{Production Volume}}$$

Estimated cost per part depends on the following:

- Minimum batch cost: specified by the machine property **Min Batch Cost**.
- Number of load bars: annual production volume divided by the [Number of Parts per Load Window](#).
- Total overhead rate: sum of the machine properties **Direct Overhead Rate** and **Indirect Overhead Rate**.
- Production volume: annual volume specified in the Production Scenario tab of the Cost Guide.

Vibratory Finishing Machine Selection

If possible, machine selection picks the smallest (by **Container Volume**) feasible machine that can accommodate, in a single cycle, a whole production batch. (The size of a production batch is specified in the Production Scenario tab of the Cost Guide.) The batch size that a given machine can accommodate in a single cycle is described in [Vibratory Finishing Batch Size](#).

If there is no feasible machine that can accommodate a production batch, machine selection picks the smallest feasible machine.

A machine is feasible only if all the following hold:

- [Vibratory Finishing Batch Size](#) for the machine is at least 1.
- Part **Volume** is less than machine **Container Volume**.
- Part mass (the product of part **Volume** and material **Density**) is no greater than machine **Weight Limit**.
- The machine container's largest two dimensions (among **Container Width**, **Container Depth**, and **Container Radius**) can accommodate one part's largest two dimensions (among **Length**, **Width**, and **Height**), for a part orientation that aligns each part dimension with a container dimension.

Cost Algorithms and Calculations

This section details how costs are calculated by aPriori. It covers formulas in the following areas:

- Surface Treatment Accounting Calculations
- Surface Treatment Yield Calculations
- Bead Blast and Sand Blast Formulas
- Shot Blast Formulas
- Shot Peen Formulas
- Painting Formula
- Passivation formulas
- Powder Coat Cart Formulas
- Wet Coat Line
- Screen Printing Formulas
- Plating Process Formulas
- Degrease Formulas
- Mask Spray Formulas
- Mask Bench Formulas
- Anodize Formulas

Surface Treatment Accounting Calculations

These formulas apply to all surface treatment processes with non-zero cycle times.

Labor Cost = Labor Time * Labor Rate / Final Yield

Labor cost is a function of the following:

- Labor time (see formula below)
- Labor rate (specified by the machine property **Labor Rate**)
- Final yield (see the formula above)

Labor Time = Cycle Time * Labor Time Standard * Number of Operators

Labor time is the product of the following:

- Cycle time (see the sections on the individual processes, below)
- Labor time standard (specified as a machine property). This value reflects the amount of time spent by machine operators in between machine cycles, including time performing maintenance and cleaning tasks as well as time pausing between tasks. The amount is expressed as a cycle time multiplier.
- Number of operators (specified by the machine property **Number of Operators**)

**Amortized Batch Setup =
(Setup Time * (Labor Rate + Direct Overhead Rate)) / Batch Size**

Amortized batch setup depends on the following:

- Setup time (specified as the machine property **Setup Time**)
- Labor rate (specified by the machine property **Labor Rate**)
- Direct overhead rate (see [Direct and Indirect Overhead](#))

- Batch size (specified in the **Production Scenario** screen of the Cost Guide, or—for some paint processes—by the PSO Painted Batch Size)

Surface Treatment Yield Calculations

These formulas apply to all surface treatment processes.

Final Yield = Final Output Volume / Local Input Volume

Final yield affects material, labor, and overhead costs per part. It is the fraction of parts created by this process in the current production scenario that will survive as good parts once any secondary processes are completed. That is, final yield is the fraction of parts created by this process that are *not* discarded as scrap parts, either by this process or by a downstream process. Final yield depends on the following:

- Final output volume is the number of parts created by this process that are *not* discarded as scrap parts, either by this process or by a downstream process. It is the product of the annual volume and number of production years, specified in the Production Scenario screen of the Cost Guide.
- Local Input volume (see the formula below). This is the total number of parts produced by this process, including all parts discarded as scrap from this process or downstream processes.

Local Input Volume = Local Output Volume + Number of Scrap Parts for This Process

Local input volume is the total number of parts produced by this process in the current scenario, including all parts discarded as scrap from this process or downstream processes. It is the sum of the following:

- Local output volume (see the formula below). This is the number of parts produced by this process, excluding parts discarded as scrap by this process, but including parts that are discarded as scrap by downstream processes.
- Number of scrap parts for this process (see the formula below)

Local Output Volume = Final Output Volume + Number of Scrap Parts Downstream

Local output volume is the number of parts produced by this process in the current scenario, excluding parts discarded as scrap by this process, but including parts that are discarded as scrap by downstream processes. It is the sum of the following:

- Final output volume is the number of parts created by this process that are *not* discarded as scrap parts, either by this process or by a downstream process. It is the product of the annual volume and number of production years, specified in the Production Scenario screen of the Cost Guide
- Number of Scrap Parts Downstream. This the number of parts discarded as scrap by downstream processes.

Number of Scrap Parts for This Process = (Local Output Volume / Local Good Part Yield) – Local Output Volume

Number of scrap parts for this process is the number of parts produced by this process in the current scenario that are discarded as scrap by this process, before any downstream process is performed on them. It is a function of the following:

- Local output volume (see the formula above). This is the number of parts produced by this process, excluding parts discarded as scrap by this process, but including parts that are discarded as scrap by downstream processes.

- Local good part yield (specified by the machine property **Good Part Yield**). This is the fraction of parts produced by this process that are not discarded as scrap by this process but may be discarded as scrap by downstream processes.

Bead Blast and Sand Blast Formulas

All costs for these processes are included in additional direct costs. Cycle time, labor time are 0.

Additional Direct Costs = Bead Blast Cost / Final Yield

Additional direct costs depend on the following:

- Bead blast cost (see the formula below)
- Final yield (see [Surface Treatment Yield Calculations](#))

**Bead Blast Cost = {
Minimum Batch Cost / Batch Size, if Batch Size * Part Weight < Minimum Batch Weight
Part Weight * Unit Weight Cost, otherwise}**

Bead blast cost depends on the following:

- Minimum batch cost (specified by the machine property **Min Batch Cost**)
- Batch size (specified in Production Scenario information)
- Part weight (product of part volume and material density, for non-assemblies)
- Minimum batch weight (specified by the machine property **Min Batch Weight**)
- Unit weight cost (specified by the machine property **Unit Weight Cost**)

Shot Blast Formulas

Shot Blast Cycle Time Calculation

Cycle Time = Process Time * Adjustment Factor

Cycle time includes setup time per part. It is the product of the following:

- Process time (see formula below)
- Adjustment factor (specified by the cost model variable **cycleTimeAdjustmentFactor**). This factor is 1 in aPiori starting point VPEs. VPE administrators can modify **cycleTimeAdjustmentFactor** in order to adjust cycle times across processes within the current VPE.

Process Time = (Surface Area * Area Allowance) + (Contour Perimeter * Perimeter Allowance)

Process time depends on the following:

- Surface area (obtained from geometry extraction)
- Area Allowance (specified by the machine property **Surface Area Allowance**)
- Contour Perimeter (flattened part perimeter, for sheet metal parts; twice the sum of part length and part width, otherwise)
- Perimeter allowance (specified by the machine property **Perimeter Allowance**)

Shot Peen Formulas

Cycle Time = Process Time * Adjustment Factor

Cycle time is the product of the following:

- Process time (see formula below)
- Adjustment factor (specified by the cost model variable **cycleTimeAdjustmentFactor**). This factor is 1 in aPriori starting point VPEs. VPE administrators can modify **cycleTimeAdjustmentFactor** in order to adjust cycle times across processes within the current VPE.

Process Time = Shot Peen Area * Surface Area Allowance

Process time is the product of the following:

- Shot peen area: by default in starting point VPEs, this is half the surface area of the part or assembly. Administrators can customize the default, and specify the percentage of the total area to be shot peened, by using the cost model variable **defaultShotPeenArea** (50% in starting point VPEs). Users can override the default on a per-part basis with the setup option **Percentage of Part/Assembly Surface Area to be Shot Peened**.
- Surface area allowance: this is the time per unit surface area required to perform the process. It is specified in sec/m² by the machine property **Surface Area Allowance**.

Note that shot peen area is converted to square meters for use in this formula.

Additional Direct Costs =

$$\text{(Total Media Cost * Additional Shot Peen Weight) / Final Yield}$$

Additional direct costs depend on the following:

- Total media cost: by default, this is looked up by **Material for Shot Peen Media** in the tool shop Tool Materials. Users can override the default with the setup option **Cost of Media**.

Tool Materials	
Edit ▾	
Media Material	Cost Per Kg (USD / kg)
Aluminium Ox...	1.30
Aluminium Sil...	0.43
Calcium Silica...	0.22
Chilled Iron	1.28
Garnet	0.78
Glass Bead	1.04
Glass Grit	0.22
Iron Silicate	0.22

Note that the default media material is specified by the cost model variable **defaultShotPeenMediaType** (iron silicate in starting point VPEs). Users can override the media material on a per-part basis with the setup option **Material for Shot Peen Media**.

- Additional shot peen weight (see formula)
- Final Yield (see [Surface Treatment Yield Calculations](#))

**Additional Shot Peen Weight =
Application Rate * Cycle Time * Fraction Non-Recyclable**

This is the mass of media consumed per part in one machine cycle. It is the product of the following:

- Application rate: specified in kg/min by the machine property **Application Rate**.
- Cycle time (see formula)
- Fraction non-recyclable: this is the fraction of used shot that *cannot* be recycled (and is thus consumed). By default this is 0.2. Administrators can customize the default, and specify the percentage of shot that *can* be recycled, with the cost model variable **percentRecycledShot** (80% in starting point VPEs). Users can override the default on a per-part basis with the setup option **Percentage of Media Recycled from 1 Part**.

Note that application rate is converted to kg/sec for use in this formula.

**Amortized Batch Setup =
(Setup Time * (Labor Rate + Direct Overhead Rate)) / Batch Size**

Amortized batch setup depends on the following:

- Setup time (specified as the machine property **Setup Time**)
- Labor rate (specified by the machine property **Labor Rate**)
- Direct overhead rate (see **Direct and Indirect Overhead**)
- Batch size (specified in the **Production Scenario** screen of the Cost Guide)

Painting Formula

All costs are included in Additional Direct Costs. Cycle time and labor time are 0.

Additional Direct Costs = (Part Surface Area * Machine Surface Area Cost) / finalYield

Additional direct costs depend on the following:

- Part surface area (obtained from geometry extraction)
- Machine Surface Area Cost (specified by the machine property Surface Area Cost)
- Final Yield (see **Surface Treatment Yield Calculations**)

Passivation formulas

Below is the cycle time formula for Passivation.

Note that starting point VPEs provide machines with **Setup Time** set to 0. Tank setup for parts with a given material is typically good for all parts with that material, so setup is usually not required for each production batch.

Cycle Time = Process Time * Adjustment Factor

Cycle time includes setup time per part. It is the product of the following:

- Process time (see formula below)
- Adjustment factor (specified by the cost model variable **cycleTimeAdjustmentFactor**). This factor is 1 in aPriori starting point VPEs. VPE

administrators can modify **cycleTimeAdjustmentFactor** in order to adjust cycle times across processes within the current VPE.

Process Time = Passivation Time / Number of Parts per Load

Process time depends on the following:

- Passivation time: time for one load, looked up in the global lookup table **passivationTreatments**. Each row of the lookup table represents a passivation treatment that uses specific solutions and temperatures. By default, aPiori finds the treatment with the shortest time that is appropriate for the part (based on the material's cut code and whether the part has been machined). If no appropriate treatment is found, the longest treatment time in the table is used. Users can override the default and specify a treatment explicitly with the PSO [Passivation Treatment](#).
- Number of parts per load: number of appropriately spaced parts that fit in the tank working zone. By default this is specified by the formula below. Users can specify this value explicitly with the PSO [Number of Components Per Passivation Tank](#).

Number of Parts per Load = Number of Parts Lengthwise * Number of Parts Widthwise

Number of appropriately spaced parts that fit in the machine working zone. If not specified explicitly with the PSO [Number of Components Per Passivation Tank](#), this depends on the following:

- Number of parts lengthwise (machine property **Machine Window Length** divided by the part's longest dimension)
- Number of parts widthwise: the number of parts at a time that are assumed to fit widthwise is the maximum number that satisfies both size and weight constraints. The size constraints are determined by the following factors:
 - Smaller two of the three part dimensions (the longest dimension is assumed to be aligned with the length of the tank)
 - Machine property **Machine Window Height**
 - Machine property **Machine Window Width**
 - Machine property **Part Spacing Factor**: this is the fraction of tightly spaced parts that can fit when the parts are spaced appropriately. Consider, in other words, the number of parts that can fit when the parts are tightly packed, with no space between them; this factor times that number of parts is the number of parts that can fit when the parts are spaced appropriately.

The weight constraints are determined by the following factors:

- Number of parts per tank (product of the number of parts per row—part length divided by **Machine Window Length**—and the number of parts widthwise)
- Part mass (part volume times material density)
- Machine property **Machine Weight Limit**

Powder Coat Cart Formulas

Powder Coat Cart Cycle Time Calculation

Cycle Time = Process Time * Adjustment Factor

Cycle time includes setup time per part. It is the product of the following:

- Process time (see formula below)
- Adjustment factor (specified by the cost model variable **cycleTimeAdjustmentFactor**). This factor is 1 in aPiori starting point VPEs. VPE administrators can modify **cycleTimeAdjustmentFactor** in order to adjust cycle times across processes within the current VPE.

Process Time = Paint Cycle Time + Mask Time

Process time is the sum of the following:

- Paint cycle time (see formula below)
- Mask time (see formula below)

Paint Cycle Time = { Oven Time/Number of Parts per Load Window, if Oven Time >= Manual Time Manual Time/Number of Parts per Load Window, otherwise}

Part cycle time depends on the following:

- Oven time (looked by the machine property **Powder Coat Thickness** in the lookup table **powderCoatCuringSchedule**.)
- manual time (see formulas below)
- Number of parts per load window (see below)

Number of Parts per Load Window

This is specified by the PSO **Number of Components per Paint Cart** or calculated as the maximum number of parts that satisfies both size and weight constraints. The size constraints are determined by the following factors:

- Part height
- Part width
- Machine property **Cart Window Height**
- Machine property **Cart Window Length**
- Machine property **Cart Spacing Factor** (the fraction of tightly packed parts that can fit when parts are spaced appropriately)

The weight constraints are determined by the following factors:

- Part mass (part volume times material density)
- Machine property **Cart Weight Limit**

Manual Time = Load Time + Unload Time + Inspection Time

Manual time is the sum of the following:

- Load time (see formula below)
- Unload time (same as load time)
- Inspection time (see formula below)

Load Time = Load Time per Part * Number of Parts per Load Window

Load time is the product of the following:

- Load time per part (looked up by part mass in the lookup table **powderCoatHandling**; load time decreases with part mass--aPriori assumes that lighter parts require less placement precision)
- Number of parts per load window (see formula above)

Inspection time = (Load Time + Oven Time + Unload Time) * Inspection Fraction

Inspection time is calculated as a fraction of load, oven, and unload time. It depends on the following:

- Load time (see formula above)
- Unload time (same as load time)
- Oven time (see formula above)
- Inspection fraction. This is specified by the cost model variable **inspectionMinutesPerHour**. The cost model variable specified as minutes of inspection time per hour of load/oven/unload time (5 in aPriori starting point VPEs). aPriori converts this value to hours of inspection time per hour of load/unload/oven time.

Mask Time = Number of Masked Features * Mask Time per Feature

Mask time is the product of the following:

- Number of masked features (number of threaded holes, by default, or specified by the PSO [Number of Masked Features](#))
- Mask time per feature (specified by the cost model variable **maskTimePerFeature**—5 seconds in aPriori starting point VPEs)

Powder Coat Cart Additional Direct Costs**Additional Direct Costs = Paint Unit Cost * Mass Used**

Additional direct costs consist of paint cost, which depends on the following:

- Paint unit cost (specified by the machine property **Paint Unit Cost**)
- Mass used (see formula below)

Mass Used = Painted Surface Area / Paint Coverage Area per Unit Mass

Mass used, in kilograms, is a function of the following:

- Painted surface area, in mm² (see formula below)
- Paint coverage area per unit mass. The formula below provides this value in ft²/lb; aPriori converts the value to mm²/kg for use in the formula for mass used.

Painted Surface Area = Fraction Painted * External Surface Area

Painted surface area is the product of the following:

- Fraction painted (1 by default, or specified by the PSO [What Fraction of Component is Painted?](#))
- External surface area (see below)

External Surface Area

External surface area is estimated as follows:

- 65% of part surface area, for tube stock

- Assembly bounding box surface area, for assemblies whose bounding box surface area is less than assembly surface area divided by the value of the cost model variable **asmBoundingBoxAreaRatio**.
- Part (or assembly) surface area, otherwise.

**Paint Coverage Area per Unit Mass =
(Powder Coat Baseline Coverage * Efficiency) / (Specific Gravity * Paint
Thickness Factor)**

Paint coverage area per unit mass, in square feet per pound, is a function of the following:

- Powder coat baseline coverage. This is the coverage in square feet of 1 pound of powder at thickness of 1 mil (specified by the cost model variable **powderCoatBaselineCoverage**, 193.2 ft² in aPriori starting point VPEs)
- Efficiency. This is the fraction of powder spray that effectively covers parts—the rest is assumed to be waste (specified by the cost model variable **powderCoatSprayEfficiency**; 0.8 in aPriori starting point VPEs)
- Specific gravity (specified by the machine property **Powder Coat Specific Gravity**)
- Paint thickness factor. This is a dimensionless quantity equal to the paint thickness in mils (specified by the machine property **Powder Coat Thickness**)

Wet Coat Line Formulas

Wet Coat Line Cycle Time Calculation

Cycle Time = Process Time * Adjustment Factor

Cycle time includes setup time per part. It is the product of the following:

- Process time (see formula below)
- Adjustment factor (specified by the cost model variable **cycleTimeAdjustmentFactor**). This factor is 1 in aPriori starting point VPEs. VPE administrators can modify **cycleTimeAdjustmentFactor** in order to adjust cycle times across processes within the current VPE.

Process Time = Paint Cycle Time + Mask Time

Process time is the sum of the following:

- Paint cycle time (see formula below)
- Mask time (see formula below)

Paint Cycle Time = Load Window Time/Number of Parts per Load Window

Part cycle time depends on the following:

- Load window time (specified in hours by the machine property **Load Window Time**; aPriori converts this to seconds). This the time it takes for the load window to complete a paint cycle, that is, progress through the entire paint line or complete a cart-based cycle (usually gated by oven/diptank time).
- Number of parts per load window (see below)

Number of Parts per Load Window

This is specified by the PSO [Number of Components per Paint Cart](#) or calculated as the maximum number of parts that satisfies both size and weight constraints. The size constraints are determined by the following factors:

- Part height
- Part width
- Machine property **Cart Window Height**
- Machine property **Cart Window Length**
- Machine property **Cart Spacing Factor** (the fraction of tightly packed parts that can fit when parts are spaced appropriately)

The weight constraints are determined by the following factors:

- Part mass (part volume times material density)
- Machine property **Cart Weight Limit**

Mask Time = Number of Masked Features * Mask Time per Feature

Mask time is the product of the following:

- Number of masked features (number of threaded holes, by default, or specified by the PSO [Number of Masked Features](#))
- Mask time per feature (specified by the cost model variable `maskTimePerFeature`—5 seconds in aPiori starting point VPEs)

Amortized Batch Setup = Setup Time / Batch Size

This is the cost per part for batch setup. It is 0 in starting point VPEs, since any required setup is assumed to be accounted for in direct overhead rates. VPE administrators can establish a nonzero value for this output by setting the machine property **Setup Time** to a nonzero value.

Amortized batch setup depends on the following:

- Setup time: specified by the machine property **Setup Time** (0 in starting point VPEs).
- Batch size: the size of a production batch. By default this is the batch size specified in the Production Scenario tab of the Cost Guide. Users can override the default with the setup option [Painted Batch Size](#).

Wet Coat Line Additional Direct Costs

Additional Direct Costs = Paint Unit Cost * Volume Used + Primer Unit Cost * Volume Used

Additional direct costs consist of paint cost, which depends on the following:

- Paint unit cost (specified by the machine property **Paint Unit Cost**)
- Volume used (see formula below)
- Primer unit cost (specified by the machine property **Primer Unit Cost**)
- Volume used (see formula below)

Volume Used = Painted Surface Area / Paint Coverage Area per Unit Volume

Volume used, in liters, is a function of the following:

- Painted surface area, in mm² (see formula below)
- Paint coverage area per unit volume (specified in m² per liter by the machine property **Paint Coverage**; aPiori converts this to mm² per liter).

Painted Surface Area = Fraction Painted * External Surface Area

Painted surface area is the product of the following:

- Fraction painted (1 by default, or specified by the PSO What Fraction of Component is Painted?)
- External surface area (see below)

External Surface Area

External surface area is estimated as follows:

- 65% of part surface area, for tube stock
- Assembly bounding box surface area, for assemblies whose bounding box surface area is less than assembly surface area divided by the value of the cost model variable `asmBoundingBoxAreaRatio`.
- Part (or assembly) surface area, otherwise.

Screen Printing Formulas

All costs for these processes are included in additional direct costs. Cycle time and labor time are 0.

Additional Direct Costs = Screen Printing Cost / Final Yield

Additional direct costs depend on the following:

- Screen printing cost (see the formula below)
- Final yield (see [Surface Treatment Yield Calculations](#))

Screen Printing Cost = Application Cost per Part * (Cost Color Multiplier + Complexity Multiplier + Size Multiplier)

Screen

- Application Cost per Part (see formula below)
- Cost Color Multiplier (see formula below). This increases the cost as the number of colors used increases.
- Complexity multiplier (0 by default, or specified by the PSO [Complexity of Print](#))
- Size multiplier: This value is looked up by screen length and width in the lookup table `screenPrintSizeMult`. Screen length and width are part length and width by default, or are specified by the PSOs [Length of Screen Print](#) and [Width of Screen Print](#).

Application Cost per Part = Application Cost * Application Area

Application cost per part is the product of the following:

- Application cost (specified in cost per meter² by the machine property **Application Cost**)
- Application area (the product of part length and width by default, or the product of the PSOs [Length of Screen Print](#) and [Width of Screen Print](#))

Cost Color Multiplier = { (1 + Color Multiplier) * (Number of Colors - 1), if Number of Colors > 1 0, otherwise}

Cost color multiplier is a function of the following:

- Color multiplier (specified by the cost model variable `screenPrintColorMultiplier`; 0.75 in aPriori starting point VPEs)

- Number of colors (specified by the cost model variable **defaultNumScreenPrintColors**, 1 in aPiori starting point VPEs; or specified by the PSO Number of Colors Used on Screen Print)

Plating Process Formulas

All plating process costs are included in additional direct costs. Cycle time and labor time are 0.

Additional Direct Costs = (Surface Area Cost + Load Unload Fee) / finalYield

Additional direct costs depend on the following:

- Surface area cost (see formula below)
- Load/unload fee (see formula below)
- Final yield (see [Surface Treatment Yield Calculations](#))

**Surface Area Cost = {
Plastic Surface Area Cost, for plastic material
Non-plastic Surface Area Cost, otherwise}**

Surface area cost depends on the following:

- Plastic surface area cost (see formula below)
- Non-plastic surface area cost (see formula below)
- Material type. aPiori counts the current part's material as plastic if either of the following hold:
 - Primary process group is Plastic Molding or Sheet Plastic.
 - Material's cut code family is 41, 42, 51, or 52.

**Plastic Surface Area Cost = Part Surface Area *
(Application Cost per Unit Area + Thickness Factor) * (1 + Plastic Plating
Surcharge)**

Plastic surface area cost depends on the following:

- Part surface area, obtained in mm² from geometry extraction, converted to meters for use in this formula.
- Application cost per unit area (specified in m² by the machine property **Application Cost Per Area**)
- Thickness factor (see formula below)
- Plastic plating surcharge (specified by the cost model variable **plasticPlatingSurcharge**; 0.1 in aPiori starting point VPEs)

**Non-plastic Surface Area Cost = Part Surface Area * (Application Cost per Unit
Area +Thickness Factor)**

Non-plastic surface area cost depends on the following:

- Part surface area, obtained in mm² from geometry extraction, converted to meters for use in this formula.
- Application cost per unit area (specified in m² by the machine property **Application Cost Per Area**)
- Thickness factor (see formula below)

Thickness Factor = {
0, if User Requested Plating Thickness <= Standard Plating Thickness
(User Requested Plating Thickness – Standard Plating Thickness) *
Extra Thickness Cost Per Area, otherwise}

Thickness factor depends on the following:

- User requested plating thickness (specified by the PSO [Specify plating thickness](#))
- Standard plating thickness (specified by the machine property **Standard Plate Thickness**)
- Extra thickness cost per area (specified by the machine property **Extra Thickness Cost Per Area**)

Load Unload Fee = {
Plating Rack Charge for Small Parts, if part is small and racked
Weight Based Fee, otherwise}

Load/unload fee is used primarily to account for the high labor costs associated with small, racked parts. (By default, parts below a particular size threshold are racked, since barrel plating would likely deform or damage the part; users can explicitly specify rack or barrel plating with the PSO [How will this part be plated?](#)). For small, racked parts, the fee is a flat cost per part; otherwise the cost is weight based. A cost model variable determines the size threshold for small parts. Load/unload fee depends on the following:

- Plating rack charge for small parts (specified by the cost model variable **platingRackChargeSmallParts**)
- Threshold for small parts. A part is considered small if its length, width, and height are all less than the cost model variable **platingBarrelSizeLimit**, 76.2mm in aPriori starting point VPEs.
- Whether the part is racked (small parts are racked by default, but see the PSO [How will this part be plated?](#))
- Weight based fee (looked up by part mass—part volume times material density—in the lookup table **platingWeightBasedHandlingFees**)

Degrease Formulas

Degrease Cycle Time Calculation

Cycle Time = Process Time * Adjustment Factor

Cycle time includes setup time per part. It is the product of the following:

- Process time (see formula below)
- Adjustment factor (specified by the cost model variable **cycleTimeAdjustmentFactor**). This factor is 1 in aPriori starting point VPEs. VPE administrators can modify **cycleTimeAdjustmentFactor** in order to adjust cycle times across processes within the current VPE.

Process Time = Load Time + Unload Time + (Conveyor Time / Number of Parts per Conveyor)

Process time depends on the following:

- Load time (looked up by part mass in the lookup table **degreaseHandling**)
- Unload time per part (same as load time)

- Conveyor time (see formula below)
- Number of parts per conveyor (see formula below)

Conveyor Time = Window Length/Conveyor Speed

Conveyor time is depends on the following:

- Window length (specified by the machine property **Conveyor Window Length**)
- Conveyor speed. By default this is the product of the following:
 - Machine property **Conveyor Speed Limit**
 - Cost model variable **conveyorSpeedRateRatio--0.1** | aPriori starting point VPEs

Users can override the default with the PSO [Speed of conveyor](#).

Number of Parts per Conveyor = Number of Parts in Entrance * Number of Parts in Row

Number of parts per conveyor depends on the following:

- Number of parts in entrance (see [Number of parts that can fit across conveyor entrance](#))
- Number of parts in row (machine property **Conveyor Window Length** divided by the part's longest dimension)

Degrease Additional Direct Costs

Additional Direct Costs = (Solvent Price * Solvent Quantity) / Final Yield

Additional direct costs depend on the following:

- Solvent price. By default, this is looked up by solvent brand in the lookup table **degreaseSolvent**. The brand is, by default, the one with the lowest price per gallon. Users can override the default brand with the PSO [Brand of degreaser](#). Users can override the looked up price with the PSO [Price of solvent](#). aPriori converts any looked up price from cost per gallon to cost per liter.
- Solvent quantity (see formula below)
- Final yield (see [Surface Treatment Yield Calculations](#))

Solvent Quantity =

$$\text{Solvent Quantity} = \frac{\text{Dilution Ratio} * \text{Water Loss per Unit Time} * \text{Conveyor Time}}{\text{Number of Parts per Conveyor}}$$

Solvent quantity is a function of the following:

- Dilution ratio. This is the fraction of water volume consisting of solvent, specified by the cost model variable **degreaseSolventRatio** (0.15 in aPriori starting point VPEs) or by the PSO [Solvent Dilution Ratio](#).
- Water loss per unit time (see formula below)
- Conveyor time (see formula above)
- Number of parts per conveyor (see formula above)

Water Loss per Unit Time = Tank Change Loss + Evaporative Loss

Water loss in liters per second depends on the following:

- Tank change loss. This is specified in liters per year by the formula below. aPriori converts this value to liters per second of working time (based on the cost model variable **workingHoursPerYear**).

- Evaporative loss (specified in liters per second by the cost model variable **dragEvaporativeLoss**, 0.000525 in aPriori starting point VPEs)

Tank Change Loss = Number of Annual Tank Changes * Tank Capacity

Tank change loss in liters per year is the product of the following:

- Number of annual tank changes (specified by the cost model variable **annualTankChange**, 2 in aPriori starting point VPEs)
- Tank capacity in liters (specified by the machine property **Tank Capacity**)

Mask Spray Formulas

Cycle Time = Process Time * Adjustment Factor

Cycle time is the product of the following:

- Process time (see formula below)
- Adjustment factor (specified by the cost model variable **cycleTimeAdjustmentFactor**). This factor is 1 in aPriori starting point VPEs. VPE administrators can modify **cycleTimeAdjustmentFactor** in order to adjust cycle times across processes within the current VPE.

Process Time = (Spraying Time * Number of Maskant Layers) + (Maskant Tack Time * (Number Maskant Layers / 2)) + Handling Time

Process time depends on the following:

- Spraying time (see formula)
- Maskant tack time: specified by the cost model variable **tackTimeAllowance** (15 minutes in starting point VPEs). After every other layer, time is allowed for the maskant to dry.
- Number of Maskant Layers: by default, the number of layers is specified by the cost model variable **defaultNumMaskantLayers** (8 in starting point VPEs); users can override the default and specify the number of layers with a setup option—see [Number of maskant layers applied in Mask Spray Inputs](#).
- Handling time (see formula)

Spraying Time = (Total Surface Area / Maskant Spraying Rate) / 2

This is spraying time per layer. It is calculated at the operation level. The cost model assumes spraying is performed by dual robots spraying simultaneously. Spraying time per layer depends on the following:

- Total surface area: surface area of the Blank GCD
- Maskant spraying rate (specified by the machine property **Spray Rate**)

Handling Time = Load Time + Unload Time

Handling time is the sum of the following:

- Load time (see formula)
- Unload time (see formula)

Load Time = Number of Handling Operators * Handling Time per Operator

Load Time is the product of the following:

- Number of handling operators: this is looked up by weight in the lookup table **tblHandlingTimes**. Part weight is material density times part volume (blank area times blank thickness).
- Handling time per operator: this is interpolated from values looked up by part weight in **tblHandlingTimes**. Part weight is material density times part volume (blank area times blank thickness).

Unload Time = Number of Handling Operators * Handling Time per Operator

Unload Time is the product of the following:

- Number of handling operators: this is looked up by weight in the lookup table **tblHandlingTimes**. Part weight is material density times part volume (blank area times blank thickness).
- Handling time per operator: this is interpolated from values looked up by part weight in **tblHandlingTimes**. Part weight is material density times part volume (blank area times blank thickness).

Expendable Tooling Cost Per Part = Maskant Quantity * Maskant Cost Per Liter * Number of Maskant Layers

Expendable tooling cost is calculated at the operation level, as Consumable Material Cost. It is the product of the following:

- Maskant quantity: this is the volume in liters of maskant consumed for a single layer. The cost model assumes that the volume consumed per square meter, for one layer of maskant, is specified by the cost model variable **defaultMaskSprayCoverage** (0.11375 liters per square meter, in starting point VPEs).
- Maskant cost per liter: this is specified by the toolshop variable **consumableMaterial_Maskant_AC850AeroDTan**.
- Number of Maskant Layers: by default, the number of layers is specified by the cost model variable **defaultNumMaskantLayers** (8 in starting point VPEs); users can override the default and specify the number of layers with a setup option—see [Number of maskant layers applied in Mask Spray Inputs](#).

Programming Cost = Programming Rate * Programming Time

By default, this is the product of the machine properties **Programming Rate** and **Programming Time**. Users can override the default on a part-part basis with a setup option—see [Programming Cost in Mask Spray Inputs](#).

Mask Bench Formulas

Cycle Time = Process Time * Adjustment Factor

Cycle time is the product of the following:

- Process time (see formula below)
- Adjustment factor (specified by the cost model variable **cycleTimeAdjustmentFactor**). This factor is 1 in aPiori starting point VPEs. VPE administrators can modify **cycleTimeAdjustmentFactor** in order to adjust cycle times across processes within the current VPE.

Process Time = Load Time + Sum of Operation Times + Unload Time

Process time depends on the following:

- Load time (see formula).
- Sum of operation times: this is the sum of the times spent on each masked feature. See the formula **Masking Time for Surfaces** and the formula **Masking Time for Holes**, below, for the per-feature masking time. The total masking time for the most recent costing is displayed in the Process Options Editor as **Total Time to Mask Surface Area**. The total surface area masked is displayed in the Process Options Editor as **Total Masked Surface Area on the Part**.
- Unload time (see formula)

Masking Time for a Surface = Base Mask Time + (Surface Area * Mask Time Per Area Allowance)

This is masking time per masked surface (Planar Face, Curved Wall, or Curved Surface). It is a linear function of the surface area to be masked. The cost model assumes the masking is effected with tape. Masking time per masked surface depends on the following:

- Base mask time (specified by the machine property **Mask Tape Time**)
- Surface area: area of the surface being masked (specified by geometry extraction)
- Mask time per area allowance (specified by the machine property **Mask Time Per Area Allowance**)

Masking Time for a Complex Hole = Base Mask Time + (Surface Area * Mask Time Per Area Allowance)

This is masking time per masked surface (Planar Face, Curved Wall, or Curved Surface). It is a linear function of the surface area to be masked. The cost model assumes the masking is effected with tape. Masking time per masked surface depends on the following:

- Base mask time (specified by the machine property **Mask Tape Time**)
- Surface area: sum of the finished areas of all the child surfaces of the hole.
- Mask time per area allowance (specified by the machine property **Mask Time Per Area Allowance**)

Masking Time for a Simple Hole

This is the masking time per Simple Hole GCD. The cost model assumes that the masking is effected with a plug. Masking time per masked hole is specified by the machine property **Mask Plug Time**.

Load Time = Number of Handling Operators * Handling Time per Operator

Load Time is the product of the following:

- Number of handling operators: this is looked up by weight in the lookup table **tblHandlingTimes**. Part weight is material density times part volume.
- Handling time per operator: this is interpolated from values looked up by part weight in **tblHandlingTimes**. Part weight is material density times part volume.

Unload Time = Number of Handling Operators * Handling Time per Operator

Unload Time is the product of the following:

- Number of handling operators: this is looked up by weight in the lookup table **tblHandlingTimes**. Part weight is material density times part volume.
- Handling time per operator: this is interpolated from values looked up by part weight in **tblHandlingTimes**. Part weight is material density times part volume.

Anodize Formulas

Cycle Time = Process Time * Adjustment Factor

Cycle time is the product of the following:

- Process time (see formula below)
- Adjustment factor (specified by the cost model variable **cycleTimeAdjustmentFactor**). This factor is 1 in aPriori starting point VPEs. VPE administrators can modify **cycleTimeAdjustmentFactor** in order to adjust cycle times across processes within the current VPE.

Process Time = Pre-treatment Time + Anodization Time + Post-treatment Time + ((Load Time + Unload Time)/ Number of Parts per Load Window)

Process time depends on the following:

- Pre-treatment time (see [Pre-treatment Formulas](#))
- Anodize time (see [Anodization Formulas](#))
- Post-treatment time (see [Post-treatment Formulas](#))
- Load time: this is the time per loadbar. By default, this is specified by the formula below. Users can override the default with the setup option [Time to load all the parts on to the loadbar](#).
- Unload time: this is the time per loadbar. By default, this is specified by the formula below. Users can override the default with the setup option [Time to load all the parts on to the loadbar](#).
- Number of parts per load window: this is the number of parts that can be hung on the loadbar. See [Number of Parts per Load Window](#).

Load Time = Number of Handling Operators * Handling Time per Operator * Number of Parts per Load Window

By default, load time per load bar is specified by this formula. Users can override the default with the setup option [Time to load all the parts on to the loadbar](#). The default value is the product of the following:

- Number of handling operators: this is looked up by weight in the lookup table **tblHandlingTimes**. Part weight is material density times part volume.
- Handling time per operator: this is interpolated from values looked up by part weight in **tblHandlingTimes**. Part weight is material density times part volume.
- Number of parts per load window: this is the number of parts that can be hung on the loadbar. See [Number of Parts per Load Window](#).

Unload Time = Number of Handling Operators Handling Time per Operator * Number of Parts per Load Window

By default, unload time per load bar is specified by this formula. Users can override the default with the setup option [Time to load all the parts on to the loadbar](#). The default value is the product of the following:

- Number of handling operators: this is looked up by weight in the lookup table `tblHandlingTimes`. Part weight is material density times part volume.
- Handling time per operator: this is interpolated from values looked up by part weight in `tblHandlingTimes`. Part weight is material density times part volume.

Number of Parts per Load Window

This is the number of parts that can be processed in one machine load, that is, the maximum number of parts that both satisfy the machine's surface area constraint (see [Anodize Machine](#)) and can fit in the loadbar window at one time. By default, the cost model uses the steps below in order to determine this number. Users can override the default value with the setup option [Number of Components per Loadbar](#).

- 1 Find the maximum number of tightly-packed, lengthwise-oriented parts that fit in the loadbar window.

$$\text{rounddown}(\text{Window Length} / \text{Part's Longest Dimension}) * \text{rounddown}(\text{Window Height} / \text{Part's Next-longest Dimension})$$

(Lengthwise orientation means that the part's longest dimension is aligned with the window's length and the part's next-longest dimension is aligned with the window's height. Tightly packed means there is no space between the parts' bounding boxes.)

- 2 Find the maximum number of tightly-packed, widthwise-oriented parts that fit.

$$\text{rounddown}(\text{Window Length} / \text{Part's Longest Dimension}) * \text{rounddown}(\text{Window Height} / \text{Part's Next-longest Dimension})$$

(Widthwise orientation means that the part's longest dimension is aligned with the window's height and the part's next-longest dimension is aligned with the window's length.)

- 3 Pick the larger of the values found in 1 and 2, above. This is the maximum number of tightly-packed parts that fit in the loadbar window.
- 4 If the maximum number of tightly-packed parts that fit in the loadbar window is 1, then the number of parts per load window is 1, and the remaining steps are unnecessary.
- 5 If the maximum number of tightly-packed parts that fit in the loadbar window is greater than 1, then multiply the maximum number of tightly packed parts by the machine property **Loadbar Spacing Factor**. (The spacing factor is the fraction of tightly packed parts that can fit when parts are spaced appropriately.)

$$\text{rounddown}(\text{Max Number of Tightly Packed Parts} * \text{Loadbar Spacing Factor})$$

The result is the maximum number of appropriately-spaced parts that fit.

- 6 Find the maximum number of parts that satisfy the machine's surface area constraint. That is, round down the result of dividing the machine property **Loadbar Max Load Surface Area** by the total surface area to be anodized on a single part (the surface area of the part minus any masked area).
- 7 The number of parts per loadbar window is the smaller of the following values:
 - The maximum number of appropriately-spaced parts that fit (the result of step 5)
 - The maximum number of parts that satisfy the machine's surface area constraint (the result of step 6)

Pre-treatment Formulas

Pre-treatment Time = Clean Time + Etch Time + Deoxidize Time + (Rinse Time * 3)

This is the sum of the cycle times for the various pre-treatment operations. Note that the cost model assumes three rinse cycles, one after each of the other pre-treatment operations:

- Clean time (see formula)
- Etch time (see formula)
- Deoxidize time (see formula)
- Rinse time (see formula)

Clean Time = Elapsed Clean Time / Number of Parts per Load Window

Clean time per part depends on the following:

- Elapsed clean time: if the Mask-Bench process is *not* included in the current routing, this is the per-load clean time. If the Mask-Bench process *is* included in the current routing, this is twice the per-load clean time. The per-load clean time, by default, is specified by the machine property **Clean Time**; users can override the default with the setup option [Clean Time for Anodizing per Loadbar](#).
- Number of parts per load window (see [Number of Parts per Load Window](#))

Etch Time = Etch Time Per Loadbar / Number of Parts per Load Window

Etch time per part depends on the following:

- Etch time per loadbar: by default, this is specified by the machine property **Etch Time**. Users can override the default with the setup option [Etch Time for Anodizing per Loadbar](#).
- Number of parts per load window (see [Number of Parts per Load Window](#))

Deoxidize Time = Elapsed Deoxidize Time / Number of Parts per Load Window

Clean time per part depends on the following:

- Elapsed deoxidize time: if the Mask-Bench process is *not* included in the current routing, this is the per-load deoxidize time. If the Mask-Bench process *is* included in the current routing, this is twice the per-load deoxidize time. The per-load deoxidize time, by default, is specified by the machine property **Deoxidize Time**; users can override the default with the setup option [Deoxidize Time for Anodizing per Loadbar](#).

- Number of parts per load window (see [Number of Parts per Load Window](#))

Rinse Time = Elapsed Rinse Time / Number of Parts per Load Window

Rinse time per part depends on the following:

- Elapsed rinse time: if the Mask-Bench process is *not* included in the current routing, this is specified by the machine property **Rinse Time**. If the Mask-Bench process *is* included in the current routing, this is twice the value of the machine property **Rinse Time**.
- Number of parts per load window (see [Number of Parts per Load Window](#))

Anodization Formulas

Anodization Time = Anodizing Time + Anodize Rinse Time + Spray Rinse Time

This is the sum of the cycle times for the various anodization operations:

- Anodizing time (see formula)
- Anodize rinse time (see formula)
- Spray rinse time (see formula)

Anodizing Time = ((720 * Coating Thickness in Mils) / Current Density in Amps per Sq Ft) + Ramp Time

Anodizing time in minutes is calculated using the “720 rule” (which is based on the guideline that it takes one minute to produce 1 mil of oxide using 720 amps per square foot). Anodizing time depends on the following:

- Coating thickness mils: by default, this specified in millimeters by the following cost model variables (depending on the type of anodizing in the current routing):
 - **anodizingCoatingThicknessTypeI** (0.01016mm in starting point VPEs)
 - **anodizingCoatingThicknessTypeII** (0.02032mm in starting point VPEs)
 - **anodizingCoatingThicknessTypeIII** (0.04064mm in starting point VPEs)

Users can override the default with the setup option [Specify Anodize Coating Thickness](#).

- Current density in amps per sq ft: by default this is the value of the machine property **Anodizing Current**. Users can override the default with the setup option [Current Applied for Anodizing Process](#).
- Ramp time: this is specified as follows:
 - Anodizing Type I: cost model variable **anodizingRampTimeHighVolt** (600 seconds in starting point VPEs)
 - Anodizing Type IB: cost model variable **anodizingRampTimeLowVolt** (300 seconds in starting point VPEs)
 - Anodizing Type IC: cost model variable **anodizingRampTimeLowVolt** (300 seconds in starting point VPEs)
 - Anodizing Type II: 0 seconds
 - Anodizing Type III: 0 seconds

Anodize Rinse Time = Elapsed Rinse Time / Number of Parts per Load Window

Rinse time per part, for the rinse that follows the type-specific Anodize operation, depends on the following:

- Elapsed rinse time: this is 3 times the value of the machine property **Rinse Time**.
- Number of parts per load window (see [Number of Parts per Load Window](#))

Spray Rinse Time = Elapsed Spray Rinse Time / Number of Parts per Load Window

Spray rinse time per part depends on the following:

- Elapsed spray rinse time (specified by the machine property **Spray Rinse Time**)
- Number of parts per load window (see [Number of Parts per Load Window](#))

Post-treatment Formulas**Post-treatment Time = Sealing Time + Dry Time**

Post-treatment time is the sum of the following:

- Sealing time (see formula)
- Dry time (see formula)

Sealing time = Elapsed Sealing Time / Number of Parts per Load Window

Sealing time per part depends on the following:

- Elapsed sealing time: by default, this is specified in minutes by the machine property **Seal Time**. Users can override the default with the setup option [Sealing Time for Anodizing per Loadbar](#).
- Number of parts per load window (see [Number of Parts per Load Window](#))

Dry Time = Elapsed Dry Time / Number of Parts per Load Window

Dry time depends on the following:

- Elapsed dry time: by default, this is specified by the machine property **Dry Time**. Users can override the default with the setup option [Drying Time for Anodizing per Loadbar](#).
- Number of parts per load window (see [Number of Parts per Load Window](#))

Additional Direct Costs for Anodizing

The Anodize cost model uses Additional Direct Costs to impose a lower bound on per-batch piece costs.

Additional Direct Costs = Additional Anodize Cost / Final Yield

- Additional anodize cost: if the cost of a batch ([Piece Cost](#) times the [Number of Parts per Load Window](#)) is no less than the machine property **Min Batch Cost**, this is 0. If the batch cost is less than **Min Batch Cost**, this is the amount by which **Min Batch Cost** exceeds the batch cost, amortized over the number of parts per load window.
- Final yield (see [Surface Treatment Yield Calculations](#))

Vibratory Finishing Formulas

Formulas for Vibratory Finishing are covered in the following sections:

- Labor Cost and Labor Time for Vibratory Finishing
- Cycle Time and Process Time for Vibratory Finishing
- Media Material Type
- Vibratory Finishing Batch Size
- Expendable Tooling for Vibratory Finishing
- Setup Time for Vibratory Finishing

Labor Cost and Labor Time for Vibratory Finishing

Labor cost and labor time are given by the following formulas:

Labor Cost = Labor Time * Labor Rate / Final Yield

Labor cost depends on the following:

- Labor time (see formula)
- Labor rate (specified by the machine property **Labor Rate**)
- Final yield (see the section on Yields in the chapter for the primary process group)

Labor Time = (Cycle Time * Number of Operators * Labor Time Standard) + Labor Handling Time

Labor time depends on the following:

- Cycle time (see formula)
- Number of operators: specified by the machine property **Number of Operators**.
- Labor time standard: specified as the machine property **Labor Time Standard**. This multiplier is used to account for otherwise unaccounted for factors that affect labor time, such as operator fatigue or time spent by the operator for cleaning or maintenance.
- Labor Handling time: this is 0 if the machine property **Automatic Part Separator** is **Yes**. Otherwise, it is the value of the cost model variable **mediaSiftTime** (900 seconds in starting point VPEs), amortized over the parts in a machine batch (see [Vibratory Finishing Batch Size](#)):

Labor Handling Time = Media Sift Time / Vibratory Finishing Batch Size

Cycle Time and Process Time for Vibratory Finishing

Cycle time and process time are given by the following formulas:

Cycle Time = Process Time * Cycle Time Adjustment Factor

Cycle time is the product of the following

- Process time: this is the sum of the child operation, Tumble Deburr. See formula for **Tumble Deburr Cycle Time**, below.
- Cycle time adjustment factor: specified by the cost model variable **cycleTimeAdjustmentFactor** (1 in starting point VPEs). Administrators can customize this value in order to globally adjust cycle times for Assembly Molding.

Tumble Deburr Cycle Time = Media Deburr Time / Vibratory Finishing Batch Size

Process time for the Vibratory Finishing process is the cycle time for the Tumble Deburr operation. This is the time for one machine cycle, amortized over the number of parts that the machine can handle at one time. It depends on the following:

- Media deburr time: this is the time for one machine cycle. It is looked up by **Media Material Type** in the tool shop table **Media** for Vibratory Finishing.

Name	Media				
Default Tool Material Name	Plastic				
Description	Attrition Rate in terms of percentage (e.g. 0.1%)				
Tool Materials					
Edit ▼					
Name	Description	Cost (USD / kg)	Density (kg / m ³)	Attrition Rate Percent	Deburr Time (s)
Ceramic	Manufact...	13.68	1,441.66	0.79	1,800.00
Plastic	Manufact...	13.16	921.01	1.53	900.00
Steel	Reused sc...	0.00	4,805.55	0.01	900.00

- Vibratory Finishing Batch Size

Media Material Type

By default, media material type is looked up by part material cut code family in lookup table **vibratoryFinishingMediaCompatibility**. Cut code family is the integer part of the value of the material property **Cut Code**.

Cut Code Family	Media
1	Steel
10	Ceramic
15	Ceramic
2	Steel
20	Steel
23	Steel
3	Steel
30	Plastic
33	Plastic
34	Plastic
4	Steel
41	Plastic
42	Plastic
5	Ceramic
51	Plastic
52	Plastic
6	Steel
7	Ceramic
8	Ceramic
9	Ceramic

If cut code family does not appear in this lookup table, or if the material does not have a cut code, the cost model uses the cost model variable **defaultMediaNoMaterialCutCode** (**Plastic** in starting point VPEs).

Users can override the default media type with the setup option **Type of Media Used**.

Vibratory Finishing Batch Size

Vibratory finishing batch size is the number of parts processed in one machine cycle. It is the maximum number of parts that the machine can accommodate, provided that it does not exceed the size of a production batch (specified in the Production Scenario tab of the Cost Guide). So the vibratory finishing batch size is the *smallest* of the following three values:

- Batch size (the size of a production batch, specified in the Production Scenario tab of the Cost Guide)
- Machine batch size volume: this is the largest number of parts that, when combined with the required media, does not exceed the machine's maximum volume capacity. See the formula below.
- Machine batch size weight: this is the largest number of parts that, when combined with the required media, does not exceed the machine's maximum volume capacity. See the formula below.

Machine Batch Size Volume = roundup(Machine Container Volume / (Part Volume + Media Volume Per Part))

This depends on the following:

- Machine container volume (see formula)
- Part volume (specified by the geometric property **Volume**)
- Media volume per part (see formula)

Machine Container Volume = Container Volume * Container Fill Percentage

This is the product of the following:

- Container volume: this specified by the machine property **Container Volume**.
- Container fill percentage: this is the maximum fraction of the **Container Volume** (specified by the machine property) that should be occupied by the parts and media together. By default in starting point VPEs, this 0.95. VPE administrators can customize the default with the cost model variable **vibratoryFinishingContainerFillPercent** (which specifies a percentage--95 in starting point VPEs). Users can override the default with the setup option **Fill Percentage of Container**.

Media Volume Per Part = Media Fill Ratio * Part Volume

Media volume per part is the product of the following:

- Media fill ratio: the ratio of the total volume of media to the total volume of parts in a vibratory finishing batch. By default, this is the value of the cost model variable **defaultVibratoryFinishingMediaRatio** (3 in starting point VPEs). Users can override the default with the setup option **Volume ratio of Media to Parts Being Utilized**.
- Part volume (specified by the geometric property **Volume**)

Machine Batch Size Weight = roundup(Machine Weight Limit / (Part Mass + Media Mass Per Part))

This depends on the following:

- Machine weight limit (specified by the machine property **Weight Limit**)

- Part mass (the product of the geometric property **Volume** and the material property **Density**)
- Media mass per part (see formula)

Media Mass Per Part = Media Density * Media Volume Per Part

Media mass per part is the product of the following:

- Media density: by default, this is the value of the toolshop property **Density** for the current **Media Material Type**. This value is based on the assumption that the media size is larger than 3/8".
Users can specify a smaller media size ($\leq 3/8$ ") by setting the setup option **Media Size** to **false**. In this case, media density is the product of the toolshop property **Density** and the cost model variable **smallMediaDensityMultiplier** (1.15 in starting point VPEs).
- Media volume per part (see formula)

Expendable Tooling for Vibratory Finishing

Expendable tooling costs are incurred for consumption of the abrasive additive and a certain fraction of media. Cost is given by the following formulas:

Expendable Tooling Cost Per Part = (Abrasive Additive Cost + Media Cost) / Final Yield

Expendable tooling cost per part depends on the following:

- Abrasive additive cost (see formula)
- Media cost (see formula)
- Final yield (see the section on Yields in the chapter for the primary process group)

Abrasive Additive Cost = (Abrasive Additive Usage Rate * Process Time * Abrasive Additive Cost Per Volume) / Vibratory Finishing Batch Size

Cost per part for abrasive additive depends on the following:

- Abrasive additive usage rate (see formula)
- Process time: see the formula **Tumble Deburr Cycle Time** in **Cycle Time and Process Time for Vibratory Finishing**.
- Abrasive additive cost per volume (see formula)
- **Vibratory Finishing Batch Size**

Note that abrasive additive cost is 0 if the setup option **Abrasive Additive Utilized** is set to **None**.

Abrasive Additive Usage Rate = Machine Container Volume * Default Abrasive Additive Ratio

The consumption rate (unit volume per unit time) for abrasive additive is the product of the following:

- Machine container volume: see the formula for **Machine Container Volume** in **Vibratory Finishing Batch Size**.

- Default abrasive additive ratio: this is the volume of additive that is consumed per unit time, expressed as a fraction of the usable container volume per unit time. It is specified by the cost model variable **defaultAbrasiveAdditiveRatio** (0.001hour^{-1} in starting point VPEs). So, for example, in starting point VPEs, the cost model assumes that the volume of additive consumed per hour is equal to $1/1000^{\text{th}}$ of the usable container volume. aPriori converts this value to a per-second value, so that abrasive additive usage rate uses standard units (mm^3/sec).

Abrasive Additive Cost Per Volume = Abrasive Cost / Abrasive Purchase Volume

Abrasive additive unit cost is 0 if the current additive name is **None** (see below).

Otherwise, it is the quotient of values looked up by abrasive name in the lookup table **vibratoryFinishingAbrasiveAdditive**:

- Cost
- Purchase Volume

vibratoryFinishingAbrasiveAdditive		
Name	Cost (USD)	Purchase Volume (mm^3)
Default Abrasive Additive	138.82	3,785,000.00
None	0.00	0.00

By default, the current additive name is specified by the cost model variable **defaultAbrasiveAdditive** (whose value is **Default Abrasive Additive** in starting point VPEs). Users can override the default with the setup option **Abrasive Additive Utilized**.

Media Cost = Media Mass Per Part *

$$\text{Media Cost Per Unit Mass} * (\text{Media Attrition Rate}/100) * \text{Process Time}$$

Media cost per part is the product of the following:

- Media mass per part: see the formula for **Media Mass Per Part** in **Vibratory Finishing Batch Size**.
- Media cost per unit mass: this is the value of the toolshop property **Cost** for the current **Media Material Type**.

Name	Media
Default Tool Material Name	Plastic
Description	Attrition Rate in terms of percentage (e.g. 0.1%)

Tool Materials						
Edit						
Name	Description	Cost (USD / kg)	Density (kg / m^3)	Attrition Rate Percent	Deburr Time (s)	
Ceramic	Manufact...	13.68	1,441.66	0.79	1,800.00	
Plastic	Manufact...	13.16	921.01	1.53	900.00	
Steel	Reused sc...	0.00	4,805.55	0.01	900.00	

- Media attrition rate: this is the percent of in-use media consumed per hour. By default, this is the value of the toolshop property **Attrition Rate Percent** for the current **Media Material Type**. This value is based on the assumption that the media size is larger than $3/8"$.

Users can specify a smaller media size ($\leq 3/8"$) by setting the setup option **Media Size**. In this case, media attrition rate is the product of the toolshop property **Attrition Rate Percent** and the cost model variable **smallMediaAttritionMultiplier** (1.25 in starting point VPEs).

Note that aPiori converts this value from percent per hour to percent per second, since process time is expressed using seconds.

- Process time: see the formula **Tumble Deburr Cycle Time** in [Cycle Time and Process Time for Vibratory Finishing](#).

Setup Time for Vibratory Finishing

Setup time per part is given by the following formula:

$$\text{Amortized Batch Setup} = (\text{Setup Time} * (\text{Labor Rate} + \text{Direct Overhead Rate})) / \text{Vibratory Finishing Batch Size}$$

Batch setup cost per part depends on the following:

- Setup time (specified as the machine property **Setup Time**)
- Labor rate (specified by the machine property **Labor Rate**)
- Direct overhead rate (see [Direct and Indirect Overhead](#))
- Vibratory finishing batch size (see [Vibratory Finishing Batch Size](#))

User Inputs

This section covers the process setup options for the following processes:

- Shot Peen Process Inputs
- Plating Processes
- Degrease
- Powder Coat Cart
- Screen Printing
- Wet Coat Line

Shot Peen Process Inputs

Shot Peen provides the following setup options:

- Percentage of Part/Assembly Surface Area to be Shot Peened
- Material for Shot Peen Media
- Cost of Media
- Percentage of Media Recycled from 1 Part

Percentage of Part/Assembly Surface Area to be Shot Peened

By default in starting point VPEs, the area shot peened in one cycle is half the surface area of the part or assembly. Administrators can customize the default, and specify the default percentage of the total area to be shot peened, by using the cost model variable **defaultShotPeenArea** (50% in starting point VPEs). Users can override the default percentage on a per-part basis with this setup option. See also [Shot Peen Formulas](#).

Material for Shot Peen Media

The default media material in starting point VPEs is iron silicate. Administrators can customize the default with the cost model variable **defaultShotPeenMediaType**. Users can override the media material on a per-part basis with this setup option. See also [Shot Peen Formulas](#).

Cost of Media

By default, media cost is looked up by [Material for Shot Peen Media](#) in the tool shop **Tool Materials**. Users can override the default, and specify a cost per Kg with this setup option. See also [Shot Peen Formulas](#).

Percentage of Media Recycled from 1 Part

By default in starting point VPEs, 80% of used shot can be recycled. Administrators can customize the default percentage with the cost model variable **percentRecycledShot**. Users can override the default on a per-part basis with this setup option. See also [Shot Peen Formulas](#).

Plating Processes Inputs

The plating processes provide the following PSOs:

- How will this part be plated?

- Specify plating thickness

How will this part be plated?

Plating method affects load/unload costs—see [Plating Process Formulas](#). By default, parts are rack plated if they are small, and barrel plated otherwise. A part is considered small if its length, width, and height are all less than the cost model variable **platingBarrelSizeLimit** (76.2mm in aPiori starting point VPEs). You can override the default and specify plating method explicitly. Select one of the following options:

- Let aPiori Decide (the default behavior described above)
- Rack Plated (load/unload costs consist of a flat fee for small, racked parts)
- Barrel Plated (load/unload costs are weight-based for large or barrel-plated parts).

Specify plating thickness

Plating thickness affects cost per unit surface area—see [Plating Process Formulas](#). By default, the thickness is specified by the machine property **Standard Plate Thickness**. Users can override the default and enter a value to specify the thickness. Select one of the following options:

- Standard thickness: default thickness described above.
- Enter desired thickness: enter a value in microns.

Degrease Inputs

The Degrease process provides the following PSOs:

- Speed of conveyor
- Number of parts that can fit across conveyor entrance
- Brand of degreaser
- Price of solvent
- Solvent Dilution Ratio

Speed of conveyor

By default, conveyor speed is the fraction of **Conveyor Speed Limit** specified by the cost model variable **conveyorSpeedRateRatio** (0.1 | aPiori starting point VPEs). You can override the default and specify the speed explicitly. Select one of the following options:

- Default: calculated by aPiori
- User Override: enter a value in mm/sec.

Number of parts that can fit across conveyor entrance

By default, the number of parts at a time that are assumed to pass through the entrance is the maximum number that satisfies both size and weight constraints. The size constraints are determined by the following factors:

- Smaller two of the three part dimensions (the longest dimension is assumed to be aligned with the length of the conveyor belt)
- Machine property **Conveyor Window Height**
- Machine property **Conveyor Window Width**
- Machine property **Conveyor Spacing Factor**: the fraction of tightly packed parts that can fit when parts are spaced appropriately. Consider, in other words, the

number of parts that can fit when the parts are tightly packed, with no space between them; this factor times that number of parts is the number of parts that can fit when the parts are spaced appropriately.

The weight constraints are determined by the following factors:

- Number of parts per window (product of the number of parts per row—part length divided by Conveyor Window Length—and the number of parts in entrance)
- Part mass (part volume times material density)
- Machine property **Conveyor Weight Limit**

You can override the default and specify the number explicitly. Select one of the following:

- Default: calculated by aPriori.
- User Override: enter a value greater than or equal to 1.

Brand of degreaser

Degreaser brand affects solvent costs (see [Degrease Additional Direct Costs](#). The default brand is the one with the lowest cost per gallon, as specified in the lookup table **degreaseSolvent**. You can override the default and specify a brand. Select one of the following options:

- Default: lowest price brand
- User Override: select a brand.

Price of solvent

Degreaser price affects solvent costs (see [Degrease Additional Direct Costs](#). The default price per gallon for a given brand is specified in the lookup table **degreaseSolvent**. You can override the default and specify a price. Select one of the following options:

- Default: price specified in lookup table **degreaseSolvent**.
- Price of Solvent: enter the price per gallon.

Solvent Dilution Ratio

Solvent dilution ratio, the fraction of water volume consisting of solvent, affects solvent costs (see [Degrease Additional Direct Costs](#). The default dilution ratio is specified by the cost model variable **degreaseSolventRatio** (0.15 in aPriori starting point VPEs). You can override the default and specify a dilution ratio explicitly. Select one of the following options:

- Default: value of the cost model variable **degreaseSolventRatio** (0.15 in aPriori starting point VPEs).
- User Override: enter a value between 0 and 1.

Manual Paint Inputs

Manual Paint provides the following options:

- Name of Primer
- Number of Primer Coats Required
- Name of Paint
- Number of Finish Coats Required

- Rate of Hand Sanding
- Rate of Hand Cleaning
- Rate of Hand Spraying Primer
- Rate of Hand Spraying Finish Coat
- Finish Coat Coverage Factor
- Number of Operators

Name of Primer

By default, the primer used is specified by the tool shop variable **Default Tool Material Name**. With this setup option, users can override the default on a per-part basis, and choose from among the primers listed in the tool shop **Tool Materials** table.

The choice of primer drives application time, cure time, and costs for consumable materials (Additional Direct Costs).

Number of Primer Coats Required

By default in starting point VPEs, the cost model assumes that a single primer coat is applied. VPE administrators can customize the default with the cost model variable **defaultNumPrimerCoats** (1 in starting point VPEs). Users can override the default on a per-part basis with this setup option.

Note that each coat is preceded by hand sanding and hand cleaning, and is followed by curing. The number of coats drives cycle time, labor time, and costs for consumable materials (Additional Direct Costs) for all these operations.

Name of Paint

By default, the paint used is specified by the tool shop variable **Default Finish Paint**. With this setup option, users can override the default on a per-part basis, and choose from among the finish paints listed in the tool shop **Tool Materials** table.

The choice of paint drives application time, cure time, and costs for consumable materials (Additional Direct Costs).

Number of Finish Coats Required

By default in starting point VPEs, the cost model assumes that a single finish coat is applied. VPE administrators can customize the default with the cost model variable **defaultNumFinishCoats** (1 in starting point VPEs). Users can override the default on a per-part basis with this setup option.

Note that each coat is preceded by hand sanding and hand cleaning, and is followed by curing. The number of coats drives cycle time, labor time, and costs for consumable materials (Additional Direct Costs) for all these operations.

Rate of Hand Sanding

By default, the sanding rate (area per unit time) is specified by the cost model variable **defaultHandSandingRate** (25,000mm²/sec in starting point VPEs). With this setup option, users can override the default on a per-part basis.

Sanding rate drives sanding cycle time and labor time.

Rate of Hand Cleaning

By default, the cleaning rate (area per unit time) is specified by the cost model variable **defaultHandCleaningRate** (30,000mm²/sec in starting point VPEs). With this setup option, users can override the default on a per-part basis.

Cleaning rate drives cleaning cycle time and labor time.

Rate of Hand Spraying Primer

By default, the primer-spraying rate (area per unit time) is specified by the cost model variable **defaultHandSprayRatePrimer** (5555.5mm²/sec in starting point VPEs). With this setup option, users can override the default on a per-part basis.

Primer-spraying rate drives cycle time and labor time for primer application.

Rate of Hand Spraying Finish Coat

By default, the finish-coat-spraying rate (area per unit time) is specified by the cost model variable **defaultHandSprayRateFinish** (5555.5mm²/sec in starting point VPEs). With this setup option, users can override the default on a per-part basis.

Finish-coat-spraying rate drives cycle time and labor time for finish coat application.

Finish Coat Coverage Factor

By default in starting point VPEs, finish coats are assumed to be applied to all of the part surface except where there are holes (which are masked by Mask Bench). With the cost model variable **defaultFinishCoatCoverageFactor** (1 in starting point VPEs), VPE administrators can customize the default, and specify the fraction of the unmasked surface area to paint. With this setup option, users can override the default on a per-part basis.

Note that this fraction also specifies the surface area fraction to sand and clean prior to finish coat application. Primer coat application, as well as sanding and cleaning prior to primer coat application, are always assumed to be performed on the entire unmasked surface area of the part.

Number of Operators

By default, the number of operators is specified by the machine property **Number of Operators**. With this setup option, users can override the default on a per-part basis. Cycle time is assumed to be inversely proportional to the number of operators.

Powder Coat Cart Inputs

Powder Cost Cart provides the following PSOs:

- Number of Components per Paint Cart
- What Fraction of Component is Painted?
- Number of Masked Features
- Painted Batch Size

Number of Components per Paint Cart

By default, the number of components per paint cart is the maximum number that satisfies appropriate size and weight constraints (see [Powder Coat Cart Cycle Time](#)

Calculation). Users can override the default and specify the number explicitly. Select one of the following options:

- Auto-computed: this is the default
- User-specified: enter a value greater than or equal to 1.

What Fraction of Component is Painted?

By default the entire (external) surface area of the part is assumed to be painted. Users can override the default and specify what fraction of the surface area is painted (which affects paint costs—see [Powder Coat Cart Additional Direct Costs](#)). Select one of the following options:

- Whole part/assembly: this is the default.
- Enter fraction painted: enter a value greater than 0 and less than or equal to 1.

Number of Masked Features

By default, the number of masked features is assumed to be the number of threaded holes (see [Powder Coat Cart Cycle Time Calculation](#)). Users can override the default and specify this value explicitly. Select one of the following options:

- All threaded holes: this is the default.
- No masking: assumes there are 0 masked features.
- Enter number of masked features: enter a value greater than or equal to 0.

Painted Batch Size

By default batch size (used to calculate amortized batch setup—see [Surface Treatment Accounting Calculations](#)) is the value specified in the Production Information screen of the Cost Guide. Users can override the default and specify a painting-specific batch size with this PSO. Select one of the following options:

- Use production batch size: this is the default.
- Specify painted batch size: enter a value greater than or equal to 1.

Screen Printing Inputs

Screen Printing provides the following PSOs:

- Number of Colors Used on Screen Print
- Length of Screen Print
- Width of Screen Print
- Complexity of Print

Number of Colors Used on Screen Print

Number of colors affects screen printing costs—see [Screen Printing Formulas](#). The default number of colors is specified by the cost model variable **defaultNumScreenPrintColors**, 1 in aPiori starting point VPEs. You can override the default and specify the number of colors explicitly. Select one of the following options:

- Default Number of Colors (specified by the cost model variable **defaultNumScreenPrintColors**, 1 in aPiori starting point VPEs)
- User Override: enter the number of colors.

Length of Screen Print

Screen print length affects screen printing costs—see [Screen Printing Formulas](#). By default, screen length is part length. You can override the default and specify the length explicitly. Select one of the following options:

- Default Screen Length (part length)
- User Override: enter the screen print length.

Width of Screen Print

Screen print width affects screen printing costs—see [Screen Printing Formulas](#). By default, screen width is part width. You can override the default and specify the width explicitly. Select one of the following options:

- Default Screen Width (part width)
- User Override: enter the screen print width.

Complexity of Print

By default, print complexity makes no contribution to the cycle time multiplier described in [Screen Printing Formulas](#). You can override the default and specify the contribution of complexity to the multiplier by selecting one of the following options:

- Basic (simple text *or* graphics): specifies a value of 0.
- Medium Complexity (simple text *and* graphics): specifies the value of the cost model variable **screenPrintComplexityMultiplier**, 0.75 in aPriori starting point VPEs.
- High Complexity (large amount of text or detailed graphics): specifies twice the value of the cost model variable **screenPrintComplexityMultiplier**.

Wet Coat Line Inputs

- Number of Components per Load Bar
- Number of Masked Features
- Painted Batch Size
- What Fraction of Component is Painted?

Number of Components per Load Bar

By default, the number of components per load bar is the maximum number that satisfies appropriate size and weight constraints (see [Wet Coat Line Cycle Time Calculation](#)). Users can override the default and specify the number explicitly. Select one of the following options:

- Auto-computed: this is the default
- User-specified: enter a value greater than or equal to 1.

Number of Masked Features

By default, the number of masked features is assumed to be the number of threaded holes (see [Wet Coat Line Cycle Time Calculation](#)). Users can override the default and specify this value explicitly. Select one of the following options:

- All threaded holes: this is the default.
- No masking: assumes there are 0 masked features.
- Enter number of masked features: enter a value greater than or equal to 0.

Painted Batch Size

By default, batch size is the value specified in the Production Scenario tab of the Cost Guide. Users can override the default and specify a painting-specific batch size with this setup option. Select one of the following options:

- Use production batch size: this is the default.
- Specify painted batch size: enter a value greater than or equal to 1.

Painted batch size is used to calculate amortized batch setup, which is the machine property **Setup Time** divided by the batch size—see [Surface Treatment Accounting Calculations](#). Note that the machine property **Setup Time** is 0 in starting point VPEs, so this setup option has *no effect* on amortized batch setup unless this machine property is modified.

What Fraction of Component is Painted?

By default the entire (external) surface area of the part is assumed to be painted. Users can override the default and specify what fraction of the surface area is painted (which affects paint costs—see [Wet Coat Line Additional Direct Costs](#)). Select one of the following options:

- Whole part/assembly: this is the default.
- Enter fraction painted: enter a value greater than 0 and less than or equal to 1.

Passivation Inputs

Passivation Treatment

Passivation treatments differ from one another with regard to the solutions and temperatures they use. The different possible treatments are listed in the global lookup table **passivationTreatments**. By default, aPriori assumes the use of the treatment that takes the shortest time among those that are appropriate for the part (based on the material's cut code and whether the part has been machined). If no appropriate treatment is found, the treatment that takes the longest time is assumed. (See [Passivation formulas](#).)

With this process setup option, you can override the default, and specify a treatment explicitly. Select a treatment from the **Select Treatment** dropdown list.

Number of Components Per Passivation Tank

By default, the number of parts passivated at one time is calculated based on a number of factors, including part dimensions, part weight, tank dimensions, and tank weight capacity (see [Passivation formulas](#)). With this process setup option, you can override the default and specify the number of parts explicitly. Enter a value greater than or equal to 1.

Mask Spray Inputs

Number of maskant layers applied

By default, the number of layers of maskant used to mask a part is specified by the cost model variable **defaultNumMaskantLayers** (8 in starting point VPEs). Users can override the default and specify the number of layers with this setup option.

Programming Cost

By default, programming cost is the product of the machine properties **Programming Rate** and **Programming Time**. With this setup option, users can override the default on a part-by-part basis, and specify the programming cost explicitly.

Anodize Inputs

The following setup options are provided by the Anodize process:

- Enable Sealing Operation
- Number of Components per Loadbar
- Time to load all the parts on to the loadbar
- Specify Anodize Coating Thickness
- Current Applied for Anodizing Process
- Clean Time for Anodizing per Loadbar
- Etch Time for Anodizing per Loadbar
- Deoxidize Time for Anodizing per Loadbar
- Sealing Time for Anodizing per Loadbar
- Drying Time for Anodizing per Loadbar

Enable Sealing Operation

By default, the Seal operation is included in Anodize routings (see [Anodize Routing](#)). With this setup option, users can override the default on a part-by-part basis. To exclude Sealing from the routing, set the option to **false**.

Number of Components per Loadbar

By default, the number of components processes at one time is determined as described in [Number of Parts per Load Window](#). With this setup option, users can override the default, and specify the number explicitly.

Time to load all the parts on to the loadbar

By default, the time to hang one load of parts on the loadbar is calculated based on the number of parts per loadbar and on values looked up by part weight in the lookup table **tblandlingTimes** (see [Anodize Formulas](#)). With this setup option, users can override the default and specify the load time per loadbar explicitly.

Specify Anodize Coating Thickness

- By default, the thickness of the oxidized layer is specified in millimeters by the following cost model variables (depending on the type of anodizing in the current routing):
 - **anodizingCoatingThicknessTypeI** (0.01016mm in starting point VPEs)
 - **anodizingCoatingThicknessTypeII** (0.02032mm in starting point VPEs)
 - **anodizingCoatingThicknessTypeIII** (0.04064mm in starting point VPEs)

See [Anodization Formulas](#). With this setup option, users can override the default on a part-by-part basis, and specify the thickness explicitly.

Current Applied for Anodizing Process

By default the anodizing current density (amps per sq ft) is specified by the machine property **Anodize Current**. See [Anodization Formulas](#). With this setup option, users can override the default on a part-by-part basis and specify the current density explicitly.

Clean Time for Anodizing per Loadbar

By default, clean time per load bar is specified by the machine property **Clean Time** (see [Pre-treatment Formulas](#)). Users can override the default on a part-by-part basis with this setup option.

Etch Time for Anodizing per Loadbar

By default, etch time per load bar is specified by the machine property **Etch Time** (see [Pre-treatment Formulas](#)). Users can override the default on a part-by-part basis with this setup option.

Deoxidize Time for Anodizing per Loadbar

By default, deoxidize time per load bar is specified by the machine property **Deoxidize Time** (see [Pre-treatment Formulas](#)). Users can override the default on a part-by-part basis with this setup option.

Sealing Time for Anodizing per Loadbar

By default, clean time per load bar is specified by the machine property **Clean Time** (see [Post-treatment Formulas](#)). Users can override the default on a part-by-part basis with this setup option.

Drying Time for Anodizing per Loadbar

By default, dry time per load bar is specified by the machine property **Dry Time** (see [Post-treatment Formulas](#)). Users can override the default on a part-by-part basis with this setup option.

Vibratory Finishing Inputs

The Vibratory Finishing process provides the following setup options:

- Volume ratio of Media to Parts Being Utilized
- Abrasive Additive Utilized
- Type of Media Used
- Media Size
- Fill Percentage of Container

Volume ratio of Media to Parts Being Utilized

Specifies the ratio of the total volume of media to the total volume of parts in a vibratory finishing batch. This affects [Expendable Tooling for Vibratory Finishing](#), as well as [Vibratory Finishing Batch Size](#).

By default, this is the value of the cost model variable **defaultVibratoryFinishingMediaRatio** (3 in starting point VPEs). Users can override the default with this setup option.

Abrasive Additive Utilized

Specifies the abrasive additive used, which affects [Expendable Tooling for Vibratory Finishing](#).

By default, the current abrasive additive is specified by the cost model variable **defaultAbrasiveAdditive** (whose value is **Default Abrasive Additive** in starting point VPEs). Users can override the default with this setup option, which allows you to select an abrasive additive from the lookup table **vibratoryFinishingAbrasiveAdditive**.

ap vibratoryFinishingAbrasiveAdditive		
Name	Cost (USD)	Purchase Volume (mm ³)
Default Abrasive Additive	138.82	3,785,000.00
None	0.00	0.00

Type of Media Used

This specifies the media material type. Because different media materials differ in cost, density, attrition rate, and deburr time, the type of media used affects [Vibratory Finishing Batch Size](#), [Cycle Time](#) and [Process Time for Vibratory Finishing](#), and [Expendable Tooling for Vibratory Finishing](#). The media material properties are stored as toolshop tool material properties:

Name	Media					
Default Tool Material Name	Plastic					
Description	Attrition Rate in terms of percentage (e.g. 0.1%)					
Tool Materials						
Edit ▼						
Name	Description	Cost (USD / kg)	Density (kg / m ³)	Attrition Rate Percent	Deburr Time (s)	
Ceramic	Manufact...	13.68	1,441.66	0.79	1,800.00	
Plastic	Manufact...	13.16	921.01	1.53	900.00	
Steel	Reused sc...	0.00	4,805.55	0.01	900.00	

By default, media material type is looked up by part material cut code family in lookup table **vibratoryFinishingMediaCompatibility**. Cut code family is the integer part of the value of the material property **Cut Code**.

Cut Code Family	Media
1	Steel
10	Ceramic
15	Ceramic
2	Steel
20	Steel
23	Steel
3	Steel
30	Plastic
33	Plastic
34	Plastic
4	Steel
41	Plastic
42	Plastic
5	Ceramic
51	Plastic
52	Plastic
6	Steel
7	Ceramic
8	Ceramic
9	Ceramic

If cut code family does not appear in this lookup table, The cost model uses the cost model variable **defaultMediaNoMaterialCutCode** (**Plastic** in starting point VPEs).

Users can override the default media type with this setup option.

Media Size

Specifies whether the media size is greater than 3/8". Media size affects the material density and attrition rate, which affect [Vibratory Finishing Batch Size](#) and [Expendable Tooling for Vibratory Finishing](#).

By default, media size is assumed to be greater than 3/8". Users can specify a smaller media size ($\leq 3/8$ ") by setting this setup option to **false**. In this case:

- Media density is the product of the toolshop property **Density** and the cost model variable **smallMediaDensityMultiplier** (1.15 in starting point VPEs).
- Media attrition rate is the product of the toolshop property **Attrition Rate Percent** and the cost model variable **smallMediaAttritionMultiplier** (1.25 in starting point VPEs)

Fill Percentage of Container

Specifies the maximum fraction of machine **Container Volume** that should be occupied by the parts and media together. This affects [Vibratory Finishing Batch Size](#) and [Expendable Tooling for Vibratory Finishing](#).

By default in starting point VPEs, this 0.95. VPE administrators can customize the default with the cost model variable **vibratoryFinishingContainerFillPercent** (which specifies a percentage--95 in starting point VPEs).

Users can override the default with this setup option.

Process Defaults and Thresholds

This section lists some of the important cost model variables.

anodizingCoatingThicknessTypeI	See Anodization Formulas.
anodizingCoatingThicknessTypeII	See Anodization Formulas.
anodizingCoatingThicknessTypeIII	See Anodization Formulas.
anodizingRampTimeHighVolt	See Anodization Formulas.
anodizingRampTimeLowVolt	See Anodization Formulas.
conveyorSpeedRateRatio	See Degrease Machine Selection and Degrease Cycle Time Calculation.
inspectionMinutesPerHour	See Powder Coat Cart Cycle Time Calculation.
maskTimePerFeature	See Powder Coat Cart Cycle Time Calculation and Wet Coat Line Cycle Time Calculation.
asmBoundingBoxAreaRatio	See Powder Coat Cart Additional Direct Costs and Wet Coat Line Additional Direct Costs.
powderCoatBaselineCoverage	See Powder Coat Cart Additional Direct Costs.
powderCoatSprayEfficiency	See Powder Coat Cart Additional Direct Costs.
screenPrintColorMultiplier	See Screen Printing Formulas.
defaultNumMaskant Layers	See Mask Spray Formulas.
defaultNumScreenPrintColors	See Screen Printing Formulas.
plasticPlatingSurcharge	See Plating Process Formulas
platingRackChargeSmallParts	See Plating Process Formulas.
platingBarrelSizeLimit	See Plating Process Formulas.
degreaseSolventRatio	See Degrease Additional Direct Costs.
workingHoursPerYear	See Degrease Additional Direct Costs.
dragEvaporativeLoss	See Degrease Additional Direct Costs.
annualTankChange	See Degrease Additional Direct Costs.

24 Other Secondary Processes Process group

This section describes the costing details and inputs that are available for the Other Secondary Processes process group. The process group includes packaging processes, testing processes, and Xray Inspection.

This chapter includes the following topics:

- Packaging Processes
 - Testing and Inspection Processes
-

Packaging Processes

Packaging overview

The Packaging process model, located in the Other Secondary Processes process group, enables estimation of expenses related to both semi-automated and manual packing of components into boxes for shipping or transport to another facility. If you have licensed the Packaging module, packaging processes are available to be included in all other Process Group routings, so that you can estimate the complete cost of manufacturing and packaging a part or assembly.

The Packaging routing available in the aPriori Baseline VPEs includes the following processes:

- Carton Forming
- Pack and Load
- Carton Sealing

The Carton Forming process estimates the time and cost to unfold a flattened carton into an open, three-dimensional state so it can contain components, and includes the cost of the carton itself. The Pack and Load process estimates the time and cost of placing components into the opened carton. It provides options to specify bagging and bubble-wrapping of component and includes the cost of bags and bubble wrap if used. The Carton Sealing process estimates the time and cost of closing and securing the carton.

Packaging costs are amortized over the total number of components contained in a carton. The size of the carton and the number of components contained in a carton both are automatically computed, but you can override them to match a specific situation.

aPriori by default will select the smallest available carton (from a table of available carton sizes) that is larger than the part (or a bag of parts, if bagging is used). aPriori then determines the number of parts/bagged set of parts that will fit in that carton; to determine this number it employs a simplified “bin nesting” algorithm that utilizes the rectangular bounding box of the part, rather than a true-part-shape 3D nesting algorithm. Process setup options are provided to allow users to override both automatically-computed carton and bag sizes and the number of items in a carton or bag, as well as many other inputs that affect cost estimates.

Packaging machines

The aPriori Baseline VPEs contain multiple Carton Forming machines, Pack and Load machines, and Carton Sealing machines (both automated and semi-automated models). There is also a “manual” instance of each machine type, to accommodate workflows that perform aspects of the packaging process using manual labor rather than automated machinery.

In each case (Carton Forming, Pack and Load, and Carton Sealing), aPriori will select the first machine that can physically accommodate the component and its chosen package size, that is also capable of running at a desired rate (cartons per unit time) if you specify one. The manual machine instance automatically will be chosen when estimating the cost of packaging large components which exceed the size limits for the semi/automated machines.

If you feel another machine better represents the actual packaging environment, you can manually select a different machine using the Edit Machine Selection window which lists the properties of all machines available at the facility. For information on how to select a different machine, see the "Selecting a machine for an operation" section of the aPriori *User Guide*.

Packaging process routings

Packaging processes (as well as Surface Treatment and Heat Treatment processes) are contained in secondary process groups. That is, these processes are applied in conjunction or subsequent to the primary manufacturing processes that are used to manufacture a part. As such, they are not available for selection when indicating the primary process group (for example, in the Production Info window or in the Select Primary Process Group window). Instead, you must Edit the process routing to include Packaging processes; they are not assigned automatically by aPriori.

To include packaging processes in a routing

- 1 In the Manufacturing Process pane, click the **Edit** menu and choose **Routing Selection...**
- 8 The Routing Selection window will appear. The last node of each routing is the Other Secondary Processes node. For the routing level of interest, **click the + symbol** to expand the Other Secondary Process node so that the top-level Packaging node is displayed.
- 9 Right-click on the Packaging node and select **Include** from the popup menu.
Note This automatically includes the Carton Forming, Pack & Load, and Carton Sealing processes organized under the Packaging node.
- 10 To remove Packaging process from a routing, right-click on the Packaging node and select **Exclude** or **Let aPriori Decide** from the popup menu.

Packaging process setup

The Packaging processes allow you to provide numerous additional inputs about how the component is packaged, which can have an impact on cost estimates. The Packaging process setup options all are accessed by right-clicking on the Processing node, not on the individual Carton Forming, Pack & Load, or Carton Sealing processes. This is because many of the inputs affect all three processes.

The Packaging process setup options window displays some automatically-computed results and provides many options:

- Include Bagging - Indicate whether components are placed in bags prior to being placed in the carton
- Include Bubble Wrap – Indicate whether bubble wrapping is used
- Components Per Bag – defaults to 1, but user can specify the number, if different
- An automatically computed “Packed Unit Size”, where a Unit is defined as a component or a bag of components, if bagging is used.

- Overrides for the automatically-computed packed unit size (Length, Width, and Height overrides)
- Carton Size and Bag Size - overrides for the automatically-selected carton size and bag size, respectively
- Carton Cost – an override for the standard (catalog) cost of the selected carton
- Bubble-Wrapping Size/Cost – an override for the standard unit cost of bubble wrap material
- Units per Carton – an override for the automatically-computed number of units per carton
- Carton Forming Rate – an override for the default carton forming rate (as specified in the machine table for the selected machine)
- Carton Sealing Rate – an override for the default carton sealing rate (as specified in the machine table for the selected machine)
- Pack & Load Time – an override for the automatically-computed loading time for a unit
- Bubble Wrapping Time – an override for the automatically-computed bubble wrapping time

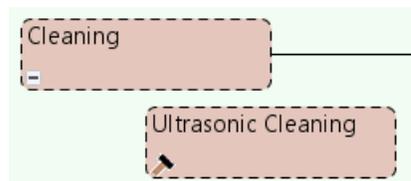
Packaging costing details

The Packaging processes use the following costing rules:

- If Packaging is included in a primary process group routing, then the costs associated with the packaging processes are computed by the Packing cost model and combined with the primary process group costs, and any other secondary processes (Heat Treatment and Surface Treatment) to produce a total manufacturing process cost.
- Material costs associated with packaging processes, such as the cost of cartons, bags, and bubble wrap, will not appear in the Material Cost field of the cost taxonomy (which is displayed in various places through aPriori, such as on the Cost Summary and Part Details tabs as well as various reports). Instead, these costs will appear as Additional Direct Costs.

Cleaning Process

This process group provides one cleaning process, **Ultrasonic Cleaning**.



Ultrasonic Cleaning

This process is automatically included only if the current routing has a node with the attribute **requiresUltrasonicCleaning**. Otherwise, this process must be manually included.

This section has the following subsections:

- Machine Selection for Ultrasonic Cleaning
- Process Time for Ultrasonic Cleaning
- Setup Options for Ultrasonic Cleaning

Machine Selection for Ultrasonic Cleaning

aPiori selects the lowest overhead machine whose basket dimensions can accommodate the dimensions of one part, assuming a buffer around the length and width of the part. The default buffer is specified by the cost model variable **basketNestingAllowance** (38.1mm in starting point VPEs). Users can override this default with the setup option **Basket Nesting Allowance** (see [Setup Options for Ultrasonic Cleaning](#)).

Overhead, here, is the given by the following:

$$\text{((Number of Batches * (Direct Overhead Rate + Indirect Overhead Rate)) / Production Volume)}$$

where

- Number of batches is the number of batches needed to achieve the production volume, given a batch size consisting of the maximum number of parts that can be accommodated by the machine (see below).
- Direct overhead rate is specified by a machine property.
- Indirect overhead rate is specified by a machine property.
- Production volume is specified in the Production Scenario tab of the Cost Guide.

The maximum number of parts that can be accommodated by the machine is the *smaller* of the following:

- Maximum number of parts that can fit in the machine basket, assuming the parts are arranged in a rectangular array with a buffer around the length and width of each part. This buffer is also added around the edges of the basket. The default buffer size is specified by the cost model variable **basketNestingAllowance** (38.1mm in starting point VPEs). Users can override this default with the setup option **Basket Nesting Allowance**.
- Maximum number of parts that satisfy the following constraint regarding the ratio of basket volume to total part surface area:

$$\text{Tank Volume in Inches / Total Part Surface Area in Inches} \geq 1$$

- Tank volume in inches. This is the product, *in inches*, of the machine properties **Machine Length**, **Machine width**, and **Machine Height**.
- Total part surface area in inches: the product of part **Surface Area** *in inches* and the number of parts.

Process Time for Ultrasonic Cleaning

Cost is based primarily on the following formulas:

$$\text{Process Time} = \text{Ultrasonic Cleaning Time Per Part} + \text{Rinse Time Per Part}$$

Process time is the sum of the following:

- Ultrasonic cleaning time per part (see formula)

- Rinse time per part: by default, this is specified by the cost model variable **ultrasonicCleaningRinseTimePerPart** (30 seconds in starting point VPEs). Users can override the default with the setup option **Ultrasonic Cleaning Rinsing Time Per Part** (see [Setup Options for Ultrasonic Cleaning](#)).

Ultrasonic Cleaning Time Per Part = (Ultrasonic Cleaning Run Time / Computed Max Number Of Parts)

Ultrasonic cleaning time per run depends on the following:

- Ultrasonic cleaning run time: by default, this is specified by the cost model variable **ultrasonicCleaningTimePerRun** (600 seconds in starting point VPEs). Users can override the default with the setup option **Ultrasonic Cleaning Time per Batch** (see [Setup Options for Ultrasonic Cleaning](#)).
- Computed max number of parts: this is the maximum number of parts that can be accommodated by the machine—see [Machine Selection for Ultrasonic Cleaning](#).

Setup Options for Ultrasonic Cleaning

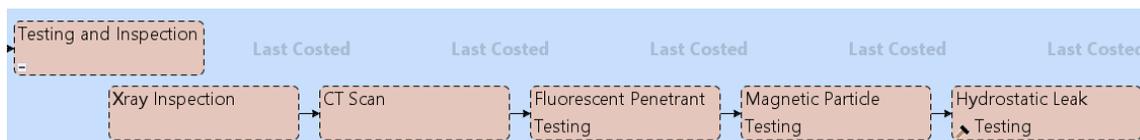
Ultrasonic cleaning provides the following setup options:

- Ultrasonic Cleaning Time per Batch: by default, this is specified by the cost model variable **ultrasonicCleaningTimePerRun** (600 seconds in starting point VPEs). Users can override the default with this setup option.
- Basket Nesting Allowance: aPiori selects the lowest overhead machine whose bed dimensions can accommodate the dimensions of one part, assuming a buffer around the length and width of the part. The default buffer is specified by the cost model variable **basketNestingAllowance** (38.1mm in starting point VPEs). Users can override this default with the setup option **Basket Nesting Allowance**.
- Ultrasonic Cleaning Rinsing Time Per Part: by default, this is specified by the cost model variable **ultrasonicCleaningRinseTimePerPart** (30 seconds in starting point VPEs). Users can override the default with this setup option.

Testing and Inspection Processes

Testing and Inspection processes include the following:

- CMM Inspection
- CT Scan
- Fluorescent Penetrant Testing
- Magnetic Penetrant Testing
- Hydrostatic Leak Testing
- Xray Inspection



All the Testing and Inspection processes select the lowest overhead machine whose **Workcenter** field is set to **Default**.

Magnetic penetrant testing can only be performed on ferromagnetic materials; the material's cut code must appear in the global lookup table **ferromagneticMaterials**.

CMM Inspection

CMM (coordinate measuring machine) inspection is the process of physically measuring a part in order to obtain precise, relative positions of various part features. aPriori's CMM Inspection process models the times and costs associated with CMM inspection, assuming the use of a touch-trigger probe. The model is described in the following sections:

- Machine Selection for CMM Inspection
- Formulas for CMM Inspection
- Setup Options for CMM Inspection

Machine Selection for CMM Inspection

aPriori selects the default machine if it is feasible; otherwise, aPriori selects the feasible machine with the lowest overhead (specified by the sum of the machine properties **Direct Overhead Rate** and **Indirect Overhead Rate**). The machine feasibility rules require that both the following hold:

- Part dimensions can be accommodated by machine bed, as specified by the machine properties **Bed Length**, **Bed Width**, and **Bed Height**.
- Part mass (the product of part volume and material density) does not exceed the machine property **Max Allowable Mass**.

Formulas for CMM Inspection

The CMM Inspection cost model relies on the formulas below.

Labor Cost = Labor Time * Labor Rate / Final Yield

Labor cost depends on the following:

- Labor time (see formula)
- Labor rate (specified by the machine property **Labor Rate**)
- Final yield (see the section on Yields in the chapter for the primary process group)

Labor Time = Cycle Time * Number of Operators * Labor Time Standard

Labor time is the product of the following:

- Cycle time (see formula)
- Number of operators: specified by the machine property **Number of Operators**.
- Labor time standard: specified as the machine property **Labor Time Standard**. This multiplier is used to account for otherwise unaccounted for factors that affect labor time, such as operator fatigue or time spent by the operator for cleaning or maintenance.

Cycle Time = Process Time * Cycle Time Adjustment Factor

Cycle time is the product of the following

- Process time: see formula.

- Cycle time adjustment factor: specified by the cost model variable **cycleTimeAdjustmentFactor** (1 in starting point VPEs). Administrators can customize this value in order to globally adjust cycle times for Assembly Molding.

**Process Time = (Number of Probe Touches Per Part *
Default CMM Probe Time * Total Sample Size) / Part Batch Size**

Process time is the number of probe touches performed per batch, amortized over the number of parts in a batch.

- Number of probe touches per part: this the number of probe touches for a single part, which is calculated based on the number of features of various types found on the part. See the formula below.
- Default CMM probe time: this is the time for a single probe touch. It is specified by the cost model variable **defaultCMMProbeTime** (2 seconds in starting point VPEs).
- Total sample size: this is the number of parts to be inspected per batch. By default, this is looked up in the lookup table **CMMInspection**, based on the following:
 - Batch size (specified in the **Production Scenario** screen of the Cost Guide)
 - Inspection type: this is **Standard Sample Sizes (AQL General Inspection)** by default in starting point VPEs. Administrators can customize the default with the cost model variable **defaultCMMInspection**. Users can override the default inspection type on a part-by-part basis with the setup option **Type of CMM Inspection (Per ANSI Standards)**--see [Setup Options for CMM Inspection](#) for more information on inspection types.

The lookup table **CMMInspection** contains information provided by the ANSI/ASQ Z1.4-2008 standard.

Batch Size	Inspection Type	Sample Size
8.00	Smaller Sample Sizes (AQL Special Inspection)	2.00
8.00	Standard Sample Sizes (AQL General Inspection)	3.00
15.00	Smaller Sample Sizes (AQL Special Inspection)	3.00
15.00	Standard Sample Sizes (AQL General Inspection)	5.00
25.00	Smaller Sample Sizes (AQL Special Inspection)	3.00
25.00	Standard Sample Sizes (AQL General Inspection)	8.00
50.00	Smaller Sample Sizes (AQL Special Inspection)	5.00
50.00	Standard Sample Sizes (AQL General Inspection)	13.00
90.00	Smaller Sample Sizes (AQL Special Inspection)	5.00
90.00	Standard Sample Sizes (AQL General Inspection)	20.00
150.00	Smaller Sample Sizes (AQL Special Inspection)	8.00
150.00	Standard Sample Sizes (AQL General Inspection)	32.00
280.00	Smaller Sample Sizes (AQL Special Inspection)	13.00
280.00	Standard Sample Sizes (AQL General Inspection)	50.00
500.00	Smaller Sample Sizes (AQL Special Inspection)	13.00
500.00	Standard Sample Sizes (AQL General Inspection)	80.00

Users can override the default sample size with the setup option **Inspected Sample Size Per Batch**—see [Setup Options for CMM Inspection](#).

- Part batch size (specified in the **Production Scenario** screen of the Cost Guide)

Number of Probe Touches Per Part =
Simple Hole Total Touches +
Planar Face Total Touches +
Curved Surface Total Touches +
Curved Wall Total Touches +
Pocket Total Touches

For each of five GCD types (SimpleHole, PlanarFace, CurvedSurface, CurvedWall, Pocket), the following formula is used:

**<GCD Type> Total Touches = Number of <GCD Type> Features *
 Number of Touches per <GCD Type> Feature * Percent of Part to be Tested**

A part's total number of touches for its GCDs of a given type is the product of the following:

- Number of <GCD type> features: this is the number of features of type <GCD type> on a single part. For example, if <GCD type> is SimpleHole, this is the number of SimpleHoles on a single part.
- Number of touches per <GCD type> feature: this is the number of probe touches performed on each feature of the type <GCD type>. For example, if <GCD type> is SimpleHole, this is the number of probe touches performed on each tested SimpleHole of the part. It is looked up by GCD type in the lookup table **CMMInspectionProbeTouches**.

Feature	Touches
Curved Surface	6.00
Curved Wall	3.00
Planar Face	4.00
Pocket	9.00
Simple Hole	4.00

- Percent of part to be tested: this is the percentage of a part's features of type <GCD type> that are tested. By default in starting point VPEs, this is 100%. VPE administrators can customize the default with the cost model variable **defaultPercentToBeTested**. Users can override the default on a per-part basis with the setup option **Percent of Part to be Tested**--see [Setup Options for CMM Inspection](#). So, for example, if the percent of the part to be tested is 50%, then half the part's SimpleHoles are tested, half the part's CurvedWalls are tested, and so forth.

Amortized Batch Setup =
(Setup Time * (Labor Rate + Direct Overhead Rate)) / Batch Size

Batch setup cost per part depends on the following:

- Setup time (specified as the machine property **Setup Time**)
- Labor rate (specified by the machine property **Labor Rate**)
- Direct overhead rate (see [Direct and Indirect Overhead](#))
- Batch size (specified in the **Production Scenario** screen of the Cost Guide)

Setup Options for CMM Inspection

The CMM Inspection process provides the following setup options:

- **Type of CMM Inspection (Per ANSI Standards):** this specifies the type of inspection to be performed, which affects the number of parts to be inspected per batch (see **Process Time** in [Formulas for CMM Inspection](#)). There are two broad inspection levels, as described in ISO 2859-1 and ANSI/ASQ Z1.4:
 - **Standard Sample Sizes (AQL General Inspection):** includes inspection levels I, II, and III.
 - **Smaller Sample Sizes (AQL Special Inspection):** includes inspection levels S1-S4. With these levels, a smaller percentage of the total batch is inspected, compared to General Inspection levels.

By default in starting point VPEs, the inspection level is **Standard Sample Sizes (AQL General Inspection)**. VPE administrators can customize the default with the cost model variable **defaultCMMInspection**. Users can override the default on a part-by-part basis with this setup option.

- **Inspected Sample Size Per Batch:** this specifies the number of parts to be inspected per batch. By default, this is looked up in the lookup table **CMMInspection**, based on inspection type and batch size (see **Process Time** in [Formulas for CMM Inspection](#)). With this setup option, users can override the default, and specify the sample size explicitly.
- **Percent of Part to be tested %:** this specifies the percentage of features of various types to be tested on each part in the tested sample. For example, if this value is 50%, then half the part's SimpleHoles are tested, half the part's CurvedWalls are tested, and so forth. The following feature types are included:
 - SimpleHole
 - PlanarFace
 - CurvedSurface
 - CurvedWall
 - Pocket

See also **Process Time** in [Formulas for CMM Inspection](#).

By default in starting point VPEs, this is 100%. VPE administrators can customize the default with the cost model variable **defaultPercentToBeTested**. Users can override the default on a per-part basis with this setup option.

CT Scan

The aPriori Starting Point VPEs define a single machine for this process.

Name	Labor Rate (USD / hr)	Setup Time...	Avg Utilization	Machine Price (USD)
Default	15.80	0.50	0.00	3,500.0

Cost is based on the following formula:

Process Time = Visual Inspection Time Standard * Part Surface Area

Process time depends on the following:

- Visual inspection time standard is inspection time per unit area (specified by the cost model variable **visualInspectTimeStandard**—5 min/m² in aPriori Starting Point VPEs)
- Part surface area (obtained from geometry extraction)

Fluorescent Penetrant Testing

The aPriori Starting Point VPEs define a single machine for this process.

Name	Workcenter	Labor Rate (USD / hr) [Ⓜ]	Setup Time (hr)	Avg Utilization [Ⓜ]	Machine Price (USD) [Ⓜ]
AIM 1836W	Default	23.72	0.00	1.00	13,500.00

Cost is based on the following formula:

$$\text{Process Time} = \text{Penetrant Dwell Time} + \text{Excess Penetrant Removal Time} + \text{Developer Dwell Time} + \text{Examination Time}$$

Process time is the sum of the following:

- Penetrant dwell time: retrieved from a node attribute of an upstream process. See the Cost Model Workbench Guide for information on node attributes. Dwell time is determined as follows:
 - If machining is permitted with the current primary process group, dwell time is the value of the node attribute **penetrantDwellTime** for the node **Machining** (10 minutes in aPriori Starting Point VPEs).
 - If machining is not permitted with the primary process group, dwell time is the value of the node attribute **penetrantDwellTime** for the primary process group's top-level node (for example, with the Transfer Die process group, the node **Sheet Metal – Transfer Die**).
 - If machining is not permitted and the primary process group's top-level node lacks the attribute **penetrantDwellTime**, dwell time is the value of the cost model variable **defaultPenetrantDwellTime** (10 minutes in aPriori Starting Point VPEs).
- Excess penetrant removal time: specified by the machine property **Excess Penetrant Removal Time** (120 seconds in aPriori Starting Point VPEs).
- Developer dwell time: retrieved from a node attribute of an upstream process. See the Cost Model Workbench Guide for information on node attributes. Dwell time is determined as follows:
 - If machining is permitted with the current primary process group, dwell time is the value of the node attribute **developerDwellTime** for the node **Machining** (10 minutes in aPriori Starting Point VPEs).
 - If machining is not permitted with the primary process group, dwell time is the value of the node attribute **developerDwellTime** for the primary process group's top-level node (for example, with the Transfer Die process group, the node **Sheet Metal – Transfer Die**).
 - If machining is not permitted and the primary process group's top-level node lacks the attribute **developerDwellTime**, dwell time is the value of the cost model variable **defaultDeveloperDwellTime** (10 minutes in aPriori Starting Point VPEs).

- Examination time: calculated as the product of the part surface area and the cost model variable **visualInspectTimeStandard** (5 min/m² in aPriori Starting Point VPEs).

Hydrostatic Leak Testing

The aPriori Starting Point VPEs define a single machine for this process.

Name	Workcenter	Labor Rate (USD / hr) [⊠]	Setup Time (hr)	Avg Utilization [⊠]	Machine Price (USD) [⊠]
Default	Default	23.72	0.00	1.00	17,500.00

Cost is based on the following formula:

$$\text{Process Time} = \text{Part Thickness} * \text{Leak Test Dwell Rate}$$

Process time is the product of the following:

- Part thickness (average thickness as determined by geometry extraction)
- Leak test dwell rate (specified by the cost model variable **leakTestDwellRate**—36 sec/mm in aPriori Starting Point VPEs)

This time is bounded above and below by the cost model variables **leakTestMaxDwellTime** and **leakTestMinDwellTime**. This maximum or minimum time is used for parts whose thickness does not fall within the range defined by the cost model variables **leakTestMinThickness** and **leakTestMaxThickness** (16.7-200mm in aPriori Starting Point VPEs).

Magnetic Penetrant Testing

Magnetic penetrant testing can only be performed on ferromagnetic materials; the material's cut code must appear in the global lookup table **ferromagneticMaterials**.

The aPriori Starting Point VPEs define a number of machines for this process.

Name	Workcenter	Labor Rate (USD / hr) [⊠]	Setup Time (hr)	Avg Utilization [⊠]	Machine Price (USD) [⊠]
WHM-4102	Default	23.72	0.00	1.00	20,000.00
WHM-4400	Default	23.72	0.00	1.00	15,000.00
WHM-4600	Default	23.72	0.00	1.00	17,500.00

Cost is based on the following formula:

$$\text{Process Time} = \text{Magnetization Time} + \text{Examination Time} + \text{Demagnetization Time}$$

Process time is the sum of the following:

- Magnetization time (specified by the machine property **Magnetization Time**—1.5 seconds in aPriori Starting VPEs)
- Examination time (calculated as the product of the part surface area and the cost model variable **visualInspectTimeStandard**—5 min/m² in aPriori Starting Point VPEs)
- Demagnetization time (specified by the machine property **Demagnetization Time**—30 seconds in aPriori Starting VPEs)

Xray Inspection Process

The aPriori Starting Point VPEs define a single machine for this process.

Name	Workcenter	Labor Rate (USD / hr) [Ⓜ]	Setup Time (hr) [Ⓜ]	Avg Utilization [Ⓜ]	Machine Price (USD) [Ⓜ]
Default	Default	23.72	0.50	0.00	3,500.00

Cost is based on the following formula:

$$\text{Process Time} = \text{Visual Inspection Time Standard} * \text{Part Surface Area}$$

Process time depends on the following:

- Visual inspection time standard is inspection time per unit area (specified by the cost model variable **visualInspectTimeStandard**—5 min/m² in aPriori Starting Point VPEs)
- Part surface area (obtained from geometry extraction)



25 User Guided Costing

aPriori provides several cost models for user-guided costing, which allows you to cost a virtual part, a part for which you do not have a CAD model. With a GCD-driven cost model, aPriori extracts from the CAD model geometric information about the part. With a user-guided cost model, in contrast, the user enters certain basic pieces of geometric information (such as part volume and the dimensions of the part's bounding box, among other values). This section introduces user-guided costing. Separate chapters provide details on each user-guided cost model (Injection Molding, Progressive Die, Stage Tooling, and Turret Press).

This chapter includes the following topics:

- Overview
 - Creating or Opening a Virtual Part
 - Using Settings from a Start Part
 - Entering Production Information
 - Entering Geometric Information
 - Administering Start Parts
-

Overview

This overview covers the following topics:

- Benefits of User-guided Costing
- User-guided VPEs and Processes
- User-guided Costing Steps
- Detailed Information on User-guided Cost Models

Benefits of User-guided Costing

User-guided cost models allow you to cost a part based on any of the following:

- A paper drawing or electronic image of the part
- A physical instance of the part that you can examine or measure
- A CAD model of a similar part

User-guided costing is useful for suppliers, cost engineers, and designers:

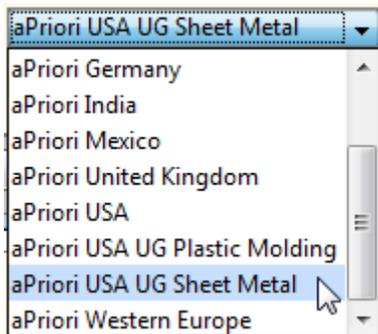
- Suppliers can develop quotes in advance of obtaining a CAD model.
- Cost engineers can perform teardowns of competitive products.
- Designers can evaluate design modifications that they haven't fully modeled.

User-guided VPEs and Processes

aPiori makes user-guided cost models available through two kinds of VPEs:

- **UG Plastic Molding** VPEs, one for each locale
- **UG Sheet Metal** VPEs, one for each locale

Each VPE and process routing can be licensed separately. When you cost a virtual part, you select one of these VPEs—see [Entering Production Information](#).



Each UG Sheet Metal VPE supports the following processes

- Turret Press (together with optional Bend Brake)
- Progressive Die
- Stage Tooling

Each UG Plastic Molding VPE supports the Injection Molding process.

Routings for all these processes can include secondary surface treatment, heat treatment, and packaging processes. These secondary processes work with both GCD-driven and user-guided cost models.

User-guided Costing Steps

Here are the main steps in performing a user-guided costing:

- 1 Create a virtual part. See [Creating or Opening a Virtual Part](#) for more information.
- 2 Use the settings from the appropriate start part—See [Using Settings from a Start Part](#) for more information.
- 3 Set the production information in the Production Scenario tab of the Cost Guide. See [Entering Production Information](#) for more information.
- 4 Enter geometric information using the Process and Machine Options tab of the Cost Guide, and the Process Options Editor. See [Entering Geometric Information](#) for more information.

Detailed Information on User-guided Cost Models

The following chapters provide in-depth descriptions of the user-guided cost models:

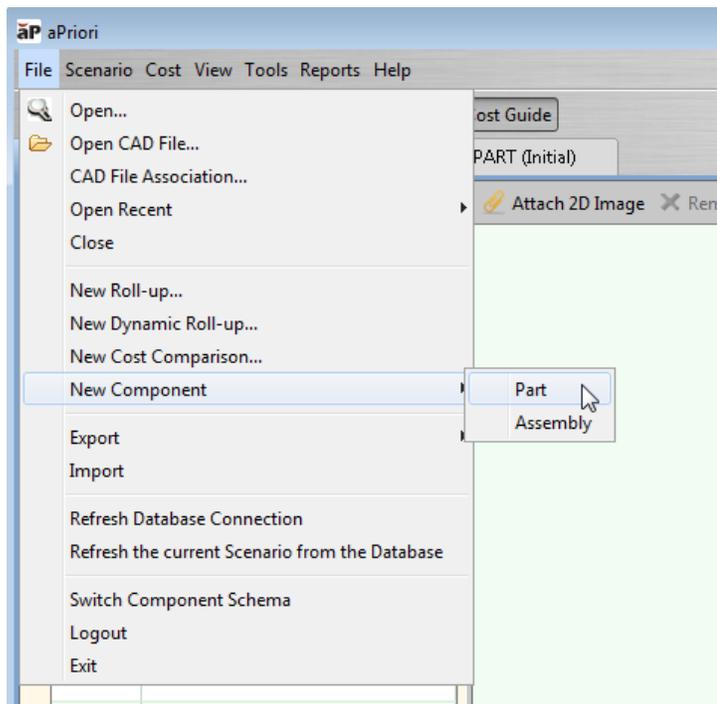
- [User Guided Injection Molding](#)
- [User Guided Sheet Metal—Progressive Die](#)
- [User Guided Sheet Metal—Stage Tooling](#)
- [User Guided Sheet Metal—Turret Press](#)

For each process, this information includes guidelines for achieving full costing, as well as descriptions of all PSOs that provide geometric information. The chapters detail how each PSO affects cost calculations.

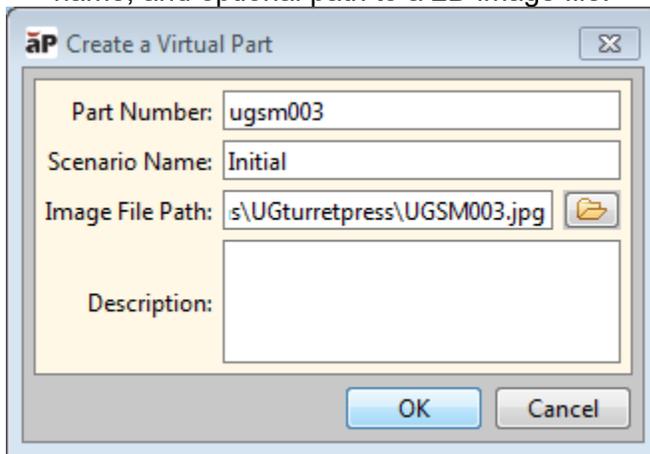
Creating or Opening a Virtual Part

To create a virtual part, follow these steps:

- 1 Select **New Component > Part** from the File menu.



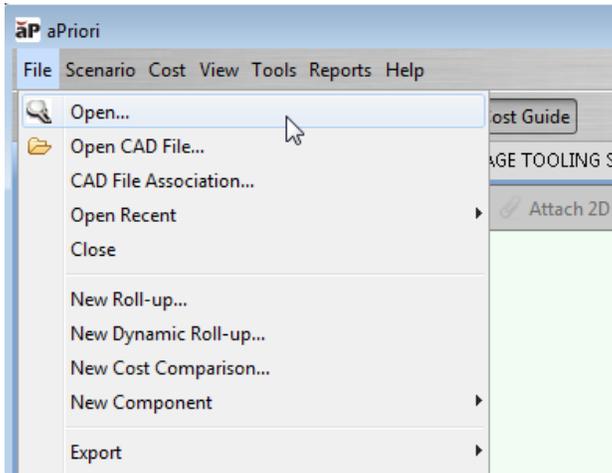
- 2 Fill in the fields in the Create a Virtual Part dialog, including a part number, scenario name, and optional path to a 2D image file.



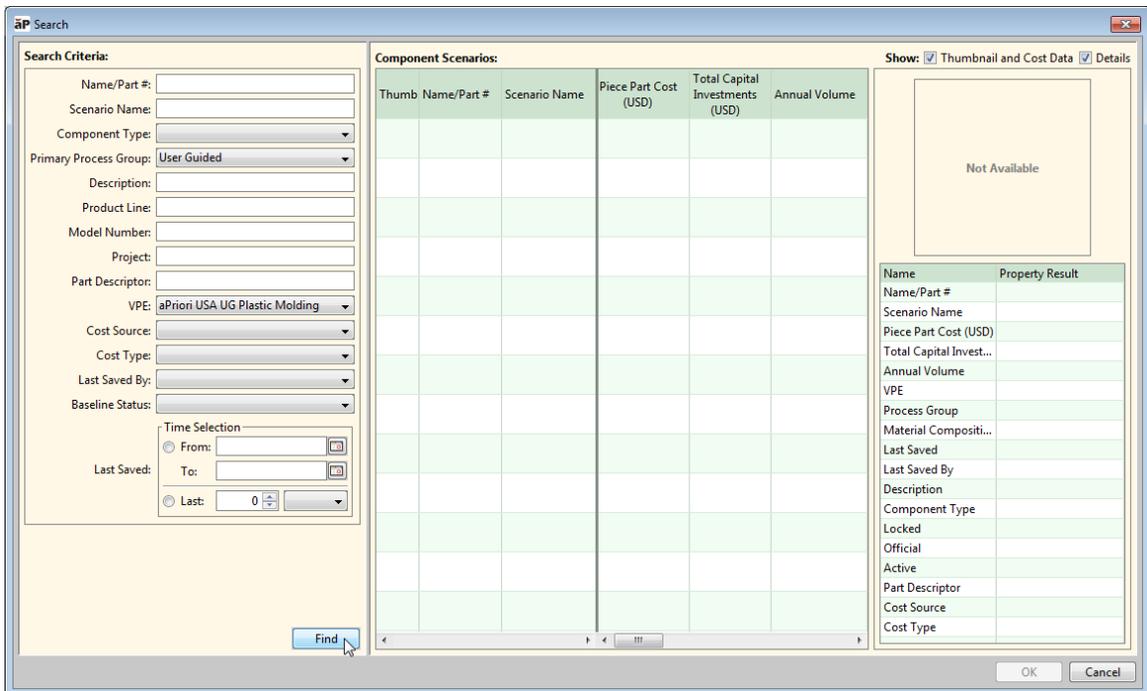
- 3 Click OK.

To open a virtual part, follow these steps:

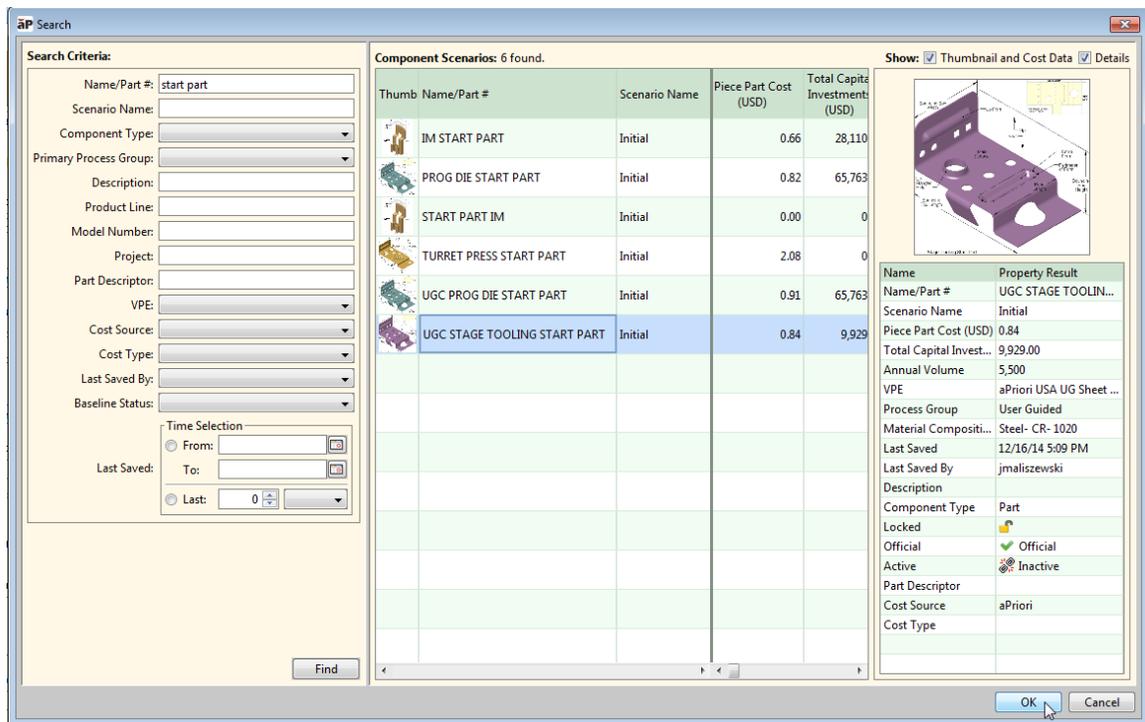
- 1 Select **Open...** from the **File** menu



2 Specify the part name or other search criteria, and click Find.



3 Select a search result and click OK.



Using Settings from a Start Part

Each user-guided cost model has an associated start part, which provides a sample user-guided costing scenario, including sample values for all required geometric PSOs. The start part's part image also provides an overview of the relevant, user-supplied, geometric values.

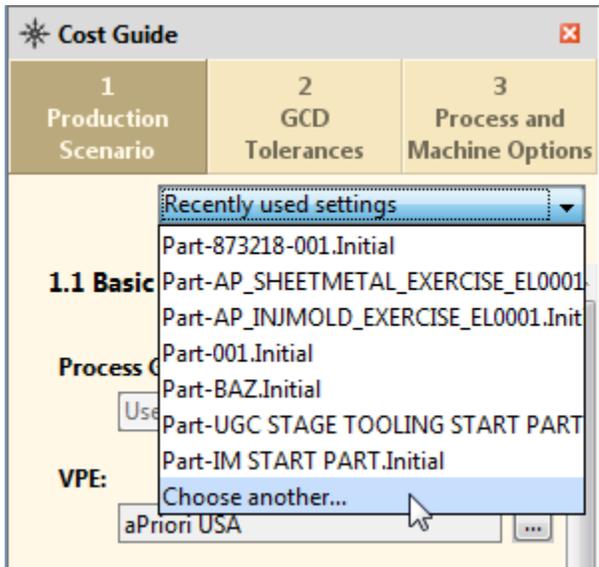
Your VPE administrator should provide you with the name of a start part that is appropriate to the VPE and process that you want to use. Instructions for VPE administrators are provided in [Administering Start Parts](#).

You can also create your own start parts for part families or similar types of geometry that may be used frequently within the company. The easiest way to do this is to create a new virtual part, use the settings from an existing start part, and then make any necessary changes. If you create a start part from scratch, you must perform an initial costing before setting geometric PSOs, in order to make the Process Options Editor available. Be sure that your start part has values for at least all required PSOs.

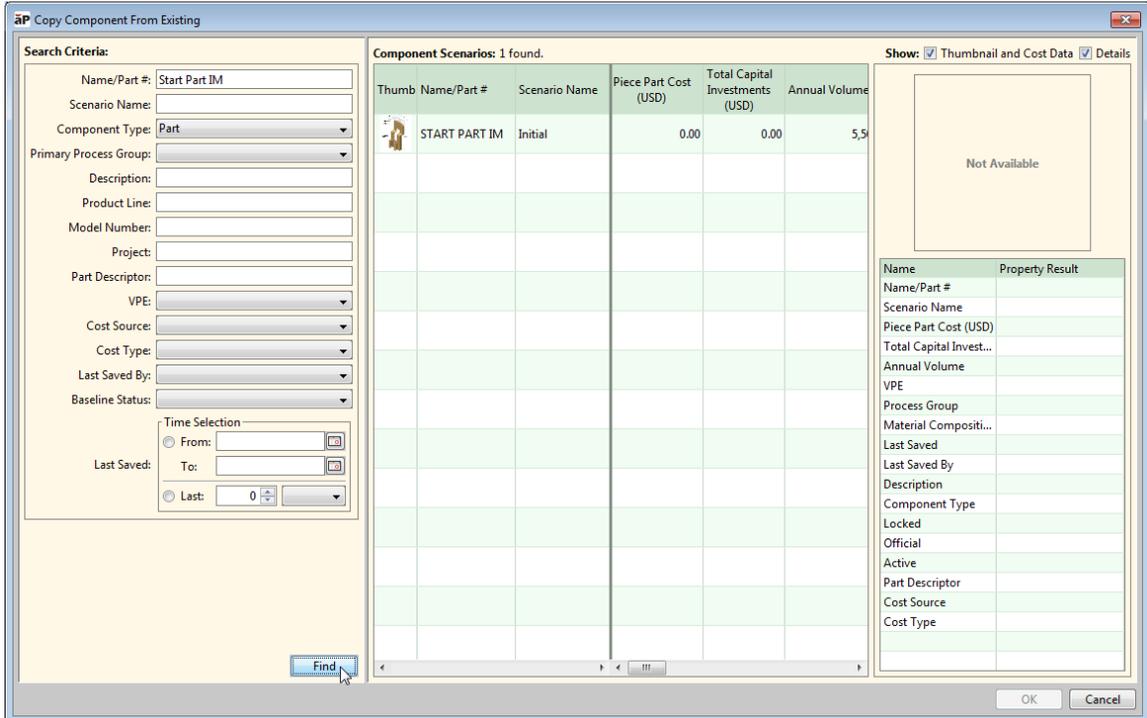
Important: Using the settings from a start part *overwrites* the image and PSO settings you have for your current scenario. You will modify these settings going forward.

Follow these steps to use the settings from a start part:

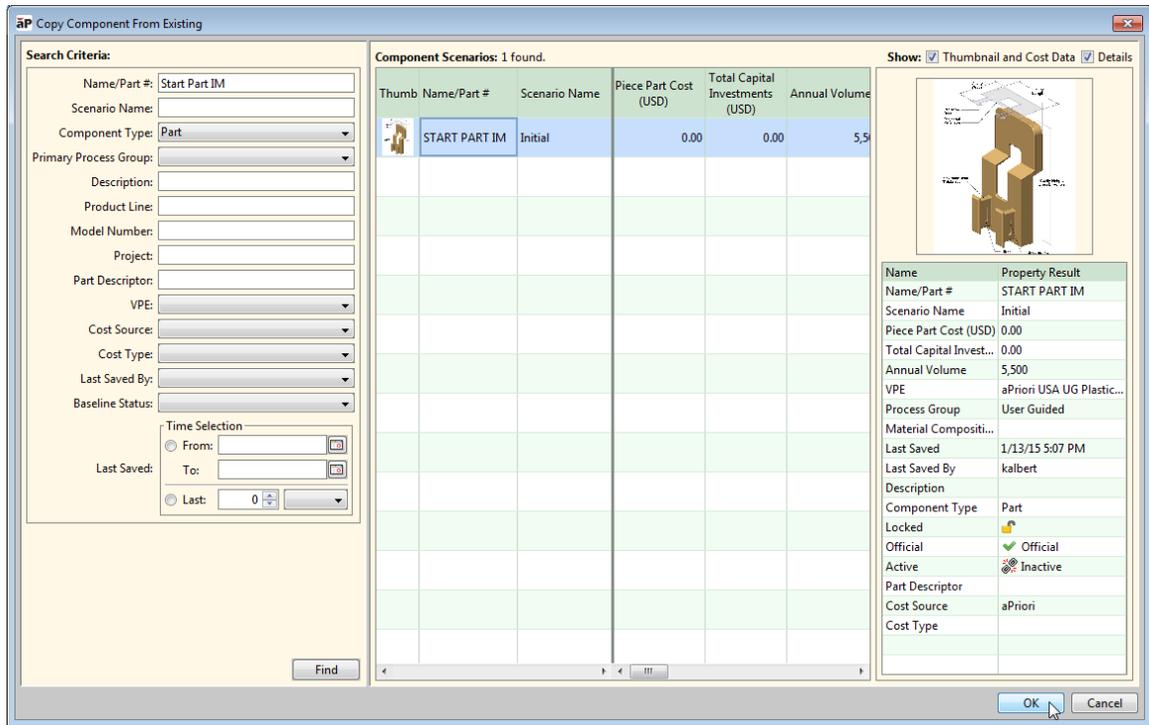
- 1 Click **Recently used settings** in the Production Scenario tab of the Cost Guide.



- 2 Select your start part from the dropdown list, or click **Choose another...**



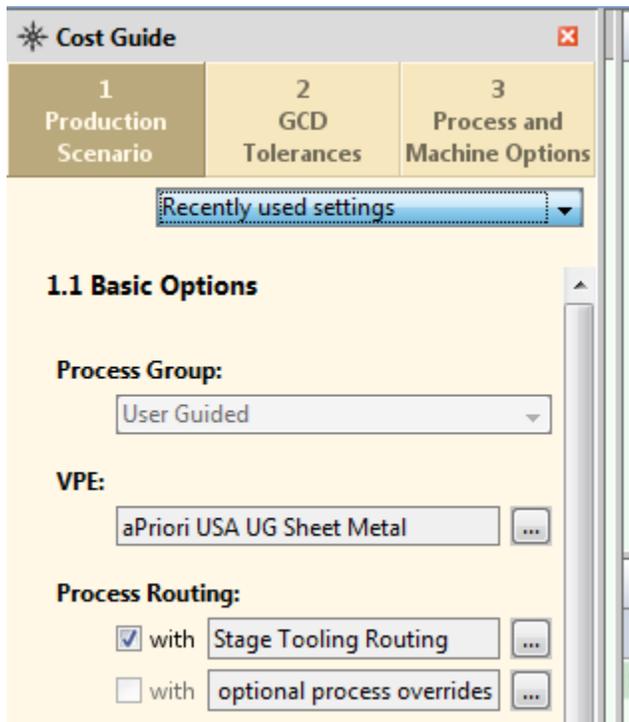
If you clicked **Choose another...**, search for your part by name, select it from the search results, and click **OK**.



Entering Production Information

Your start part automatically sets the following production information in the Production Scenario tab of the Cost Guide:

- VPE for the cost model that you want to use—see [User-guided VPEs and Processes](#)
- Process Group **User Guided**
- Process routing for the routing that you want to use—see [User-guided VPEs and Processes](#)



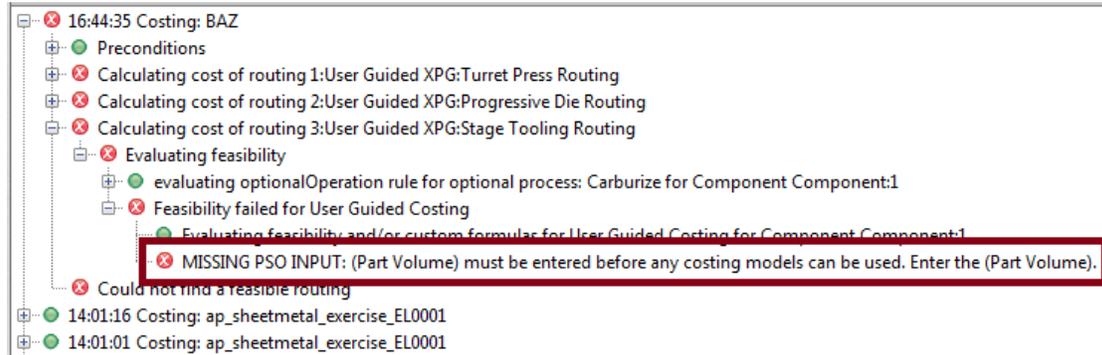
Enter the rest of the production information for user-guided costing just as you would for GCD-driven costing.

Entering Geometric Information

You enter geometric information by specifying values for certain Process Setup Options (PSOs). For each process, several geometric PSOs are required. Your start part has supplied values for all these required PSOs. If values are not present for required PSOs, the part will fail to cost. You can obtain information about the required inputs that you have not provided by hovering over the relevant red x, , in the Manufacturing Process pane, or by expanding the tree in the message pane.

Manufacturing Process		
Edit View Primary Process Group: User Guided Material: Steel- CR- 1020 (aPriori USA UG Sheet Metal) ?		
Status	Process Step	VPE
	 UG002	aPriori USA UG Sheet Metal
	 User Guided Costing	aPriori USA UG Sheet Metal
MISSING PSO INPUT: (Part Volume) must be entered before any costing models can be used. Enter the (Part Volume).		

User Guided Costing

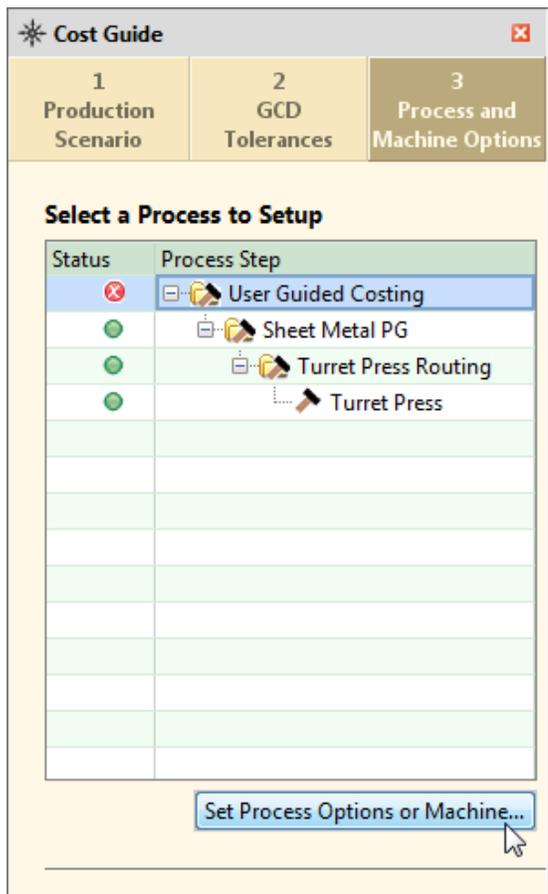


A *conditionally required* PSO is one that is required if you or your start part has entered a nonzero value for a particular, related PSO. For example, with user-guided Turret Press, Total Perimeter of Holes is required if you have entered a nonzero value for Number of Holes.

The part image for your start part provides an overview of the relevant, user-supplied, geometric values

Follow these steps to enter geometric information:

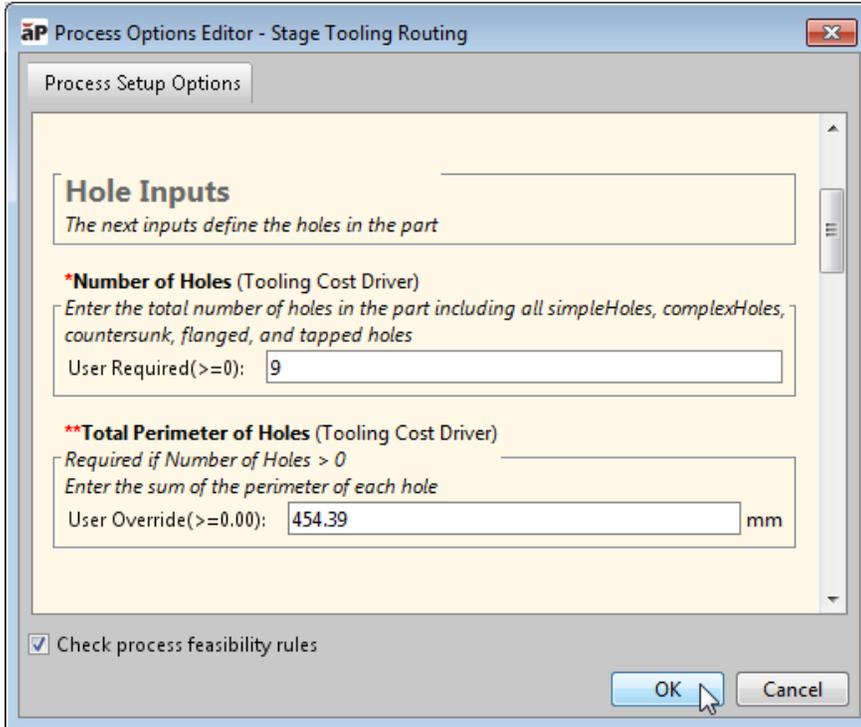
- 1 Click the Process and Machine Options tab of the Cost Guide. Geometric PSOs are associated with various routing nodes, arranged in a tree. Expand the tree; the recommended workflow is to work from the top of the tree to the bottom. You must set the PSOs for each node. Select the desired node and click **Set Process Options or Machine....**



- 2 In the Process Options Editor, enter a value for each required PSO by modifying the start part value. Also enter a value for each conditionally required PSO, if you or your start part entered a nonzero value for its associated PSO. Enter values for optional PSOs to override defaults or provide additional geometric information.

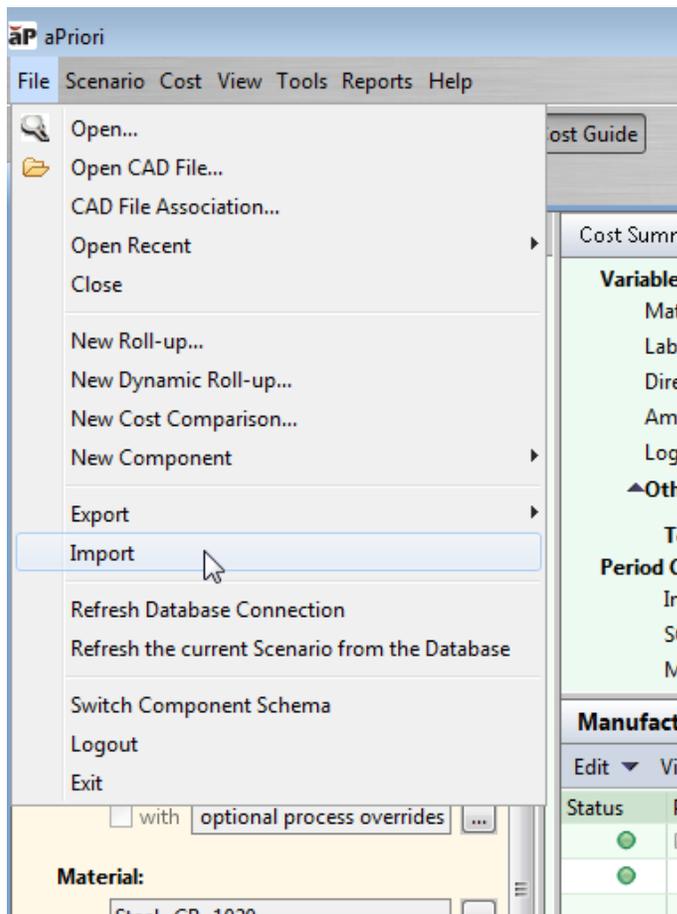
Required PSOs are marked with *. Conditionally required PSO are marked with **.

When you're done entering information, click **OK**.



- 3 If you haven't entered information for every PSO node, select a node, click **Set Process Options or Machine...** and go back to the previous step.

The information that you've entered so far is displayed in the Process and Machine Options tab (drag the border of the Cost Guide, if necessary, to display the values). Click **Revise** to bring up the Process Options Editor.



The imported start parts will have the following names:

- AP UGC INJ MOLDING START PART
- AP UGC TURRET PRESS START PART
- AP UGC STAGE TOOLING START PART
- AP UGC PROG DIE START PART

Administrators can also create their own start parts for part families or similar types of geometry that may be used frequently within the company. One way to do this is to create a new virtual part, import the settings from an existing start part, and make any necessary changes. Be sure that your start part has values for at least all required PSOs. If you create a start part from scratch, you must perform an initial costing before setting geometric PSOs, in order to make the Process Options Editor available.

Note: Start parts may not reflect the names of the VPEs that you currently have installed at your company. This is indicated by a VPE name with strikethrough text as shown in the following screenshot:

Manufacturing Process			
Edit ▾		Primary Process Group: User Guided	Material: <none> (<none>) ?
Status	Process Step	VPE	Machine
✘	AP UGC INJECTION MOLDING	aPriori USA UG Plastic Molding	
✘	User Guided	aPriori USA UG Plastic Molding	

To address this issue, simply save as a new scenario, change to your company's VPE, cost the start part, and save it.



26 User Guided Injection Molding

This section describes the costing details and inputs that are available for User Guided Injection Molding (IM). For this process, aPriori estimates manufacturing times and costs for single-shot, molded parts (including cost estimates for manufacturing the required mold). The routing can include secondary surface treatment and packaging processes (if you have licensed these modules). Since this is not a GCD-driven cost model, cost estimates are not based on a CAD model and geometry extraction; rather, basic geometric inputs (such as part dimensions and undercut depths) are provided by the user. See [User Guided Costing](#) for an introduction to user-guided costing. See [Plastic Molding Process Group](#) for the GCD-driven IM cost model.

This chapter includes the following topics:

- Cost Model Overview
 - Geometric User Inputs
 - Cost Algorithms and Calculations
 - Additional User Inputs
 - Process Defaults and Thresholds
-

Cost Model Overview

This document describes the User Guided Injection Molding cost model. With some notable differences, this Cost Model is based on the same calculations as the GCD-driven cost model for Injection Molding found in the Plastic Molding process group.

Important differences between user guided IM and the GCD-driven model include the following:

- The concept of *undercuts* replaces the analysis of slides and slide bundles used in the GCD-driven model.
- Tooling is always assumed to be constructed with a Standard Mold Base. Custom made tooling is not supported.
- Manual overrides of tool dimensions are not available in the user guided model.

In general, plastic molding costs are determined by aggregating material, labor, machine, and tooling costs.

This overview section summarizes assumptions and limitations of the following aspects of the model:

- General Process
- Part Geometry
- Materials and Stock Forms
- Machines
- Tooling

General Process

aPriori's plastic molding process model assumes all the following:

- Single part (multiple mold cavities are supported, but each cavity must handle the identical part design)
- Single shot
- Single material
- Single color
- Two or three plate mold

IM supports thermoplastic material only.

Subprocesses and Machine Types

The model also does *not* support any of the following subprocesses and machine types:

- In-mold labeling
- In-mold assembled components
- Insert molding
- Co-molding

- Over molding
- Stack molding

Material Utilization

The process model assumes the following regarding material utilization:

- Flash is minimized due to the high clamping capabilities of the machines.
- Some setup time is required to test molding. All parts created during mold testing are scrapped, and costs for this scrap are included in the overall cost of the part. See [Other Direct Costs](#).
- During processing, individual part waste is a function of the required volume of runners and the available regrind amount. The percent utilization of the process is also a function of the average utilization of the machine, as well as mold efficiency. Typical utilization is 95%. See [Material Utilization](#) for more information.

Additional Limitations

The model

- *Does not* attempt to estimate the required number of hot drops. You must enter this number manually by using [Process Setup Options](#).
- Does not account for part defects like sink marks, short shots, bubbles, warping, or ejector marks.

Part Geometry

Feasible geometries for IM are limited only by machine capabilities. A part is geometrically feasible for IM if and only if some machine that is included in the VPE satisfies both the following requirements:

- It is able to accommodate the horizontal and vertical dimensions of the mold base required for the part.
- It is able to provide the clamp force required for the part. (The required clamp force is a function of the part's geometry as well as the material to be used.)

See [Machine Feasibility and Selection](#) for more information on machine selection.

Some special process setup options are provided as a substitute for the geometry extraction that is performed with the GCD-driven cost model—See [Geometric User Inputs](#).

Materials and Stock Forms

The IM cost model only supports the molding of thermoplastic materials. The cost model assumes that the material is delivered in pellet form. The model relies on the following properties of the various supported materials:

- `Unit Cost (USD/kg)`: influences total material cost (volumetric).
- `Density (kg/m3)`: influences total material cost (volumetric).
- `Eject Deflection Temp (°C)`: influences part cooling time.
- `Melting Temp (°C)`: influences part cooling time.

- Mold Temp (°C): influences part cooling time.
- Thermal Diffusivity (mm²/s): influences part cooling time.

See Cost Algorithms and Calculations for more information.

Machines

The plastic molding machines in the aPriori baseline VPE only cover single-shot, single-part, single-material, single-color molding. The cost model assumes that the hopper and barrel are large enough to accommodate the required shot size.

Brand names of IM machines in the baseline VPE include the following:

- Arburg
- Engel
- Kawaguchi
- KraussMaffei
- Milacron
- Netstal
- Toyo

The characteristics of these machines fall into the following ranges:

Machine Characteristic	Low End	High End
Overhead Rate	\$23.19 per hour	
Dry Cycle Time (Ejection Time)	1.1 seconds	
Injection Rate	64,000 mm ³ per second	3,710,000 mm ³ per second
Clamping Force	300 kN	55,000 kN
Max Mold Height	300 millimeters	3,300 millimeters
Min Mold Height	150 millimeters	1,500 millimeters
Tie Bar Distance (Horizontal and Vertical)	221 millimeters	2,500 millimeters

See [Machine Feasibility and Selection](#) for more information.

Tooling

The tooling model supports single cavity and multi-cavity molds for single parts.

Molds can be machined out of the following types of material:

- P20 Tool Steel
- H13 Tool Steel
- Stainless Steel
- Carbon Steel
- Aluminum

- Epoxy

Note that Epoxy is not an option for the action and ejector box material.

Only catalog mold bases are supported.

The Injection Molding tooling model aggregates costs in the following categories associated with hard tooling, and presents them as a bill of materials:

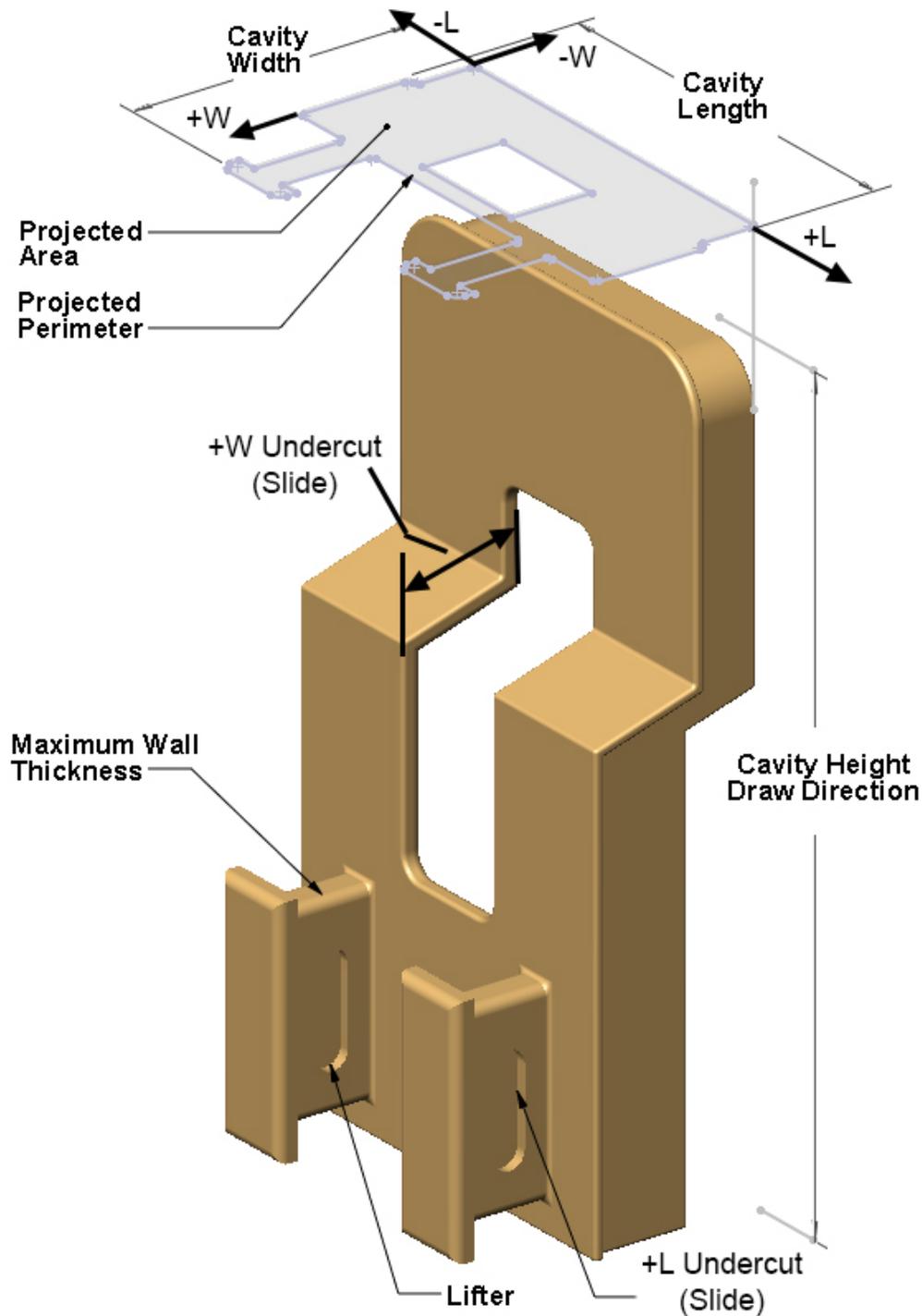
- Material costs: raw materials for core and cavity plates, ejector boxes, actions, and EDM carbon
- Standard purchased item costs: items such as ejector guide pins, locating rings, stop pins, sleeve pins, water hoses, etc.
- Labor costs: labor associated with machining, assembly, mold design, finishing/polishing, spotting, tryout, and CMM inspection
- Miscellaneous costs: heat treatment, plating, stress relief, texture, freight, markup/profit

See [Tooling Cost](#) for more information.

Geometric User Inputs

This section covers the Process Setup Options (PSOs) that serve as substitutes for the geometry extraction performed by GCD-driven cost models.

The following start part image provides an overview of the relevant, user-supplied, geometric values.



Follow these guidelines to ensure that your part will cost:

- 1 Create a virtual part and use the settings from an appropriate start part (select or search for the start part scenario from the **Recently Used Settings** menu of the Cost Guide's Production Scenario tab—see [Using Settings from a Start Part](#)).
- 2 Open the **User Guided** node in the Process and Machine Options tab of the Cost Guide. Supply a nonzero value for the required PSO Part Volume.

3 Open the **Plastic Molding PG** node in the Process and Machine Options tab of the Cost Guide. Supply a nonzero value for all the required PSOs:

- Cavity Length
- Cavity Width
- Cavity Height

See [Part Length, Width, and Height](#).

4 Open the **IM Routing** node. Supply a value that is greater than or equal to 0 for all the required PSOs:

- Part Projected Area
- Part Projected Perimeter
- Average Part Thickness
- Max Part Thickness
- Part Surface Area

See [Part Surface Area, Projected Area and Perimeter, and Wall Thickness](#).

In addition, important optional inputs are described in the following sections:

- [Undercut Depths](#)
- [Number of Lifters, Inserts and Unscrewing Mechanism](#)

Additional IM PSOs are described in [Additional User Inputs](#).

Part Volume

***Part Volume** (Piece Part & Tooling Cost Driver)

Used to calculate part mass and various values impacting part and tooling cost

User Override(>=1.000): mm³

The required PSO **Part Volume** is associated with the routing node **User Guided Costing**. This value contributes to piece part and tooling costs. In particular, part volume is used to determine material utilization (see [Material Utilization](#)) and shot size (see [Required Shot Size](#)).

This is a required input. Enter a value greater than 0.

Part Length, Width, and Height

Cavity Length** (Piece Part & Tooling Cost Driver)*Longest dimension of part in the plane normal to the draw direction*User Required(≥ 0.100): mmCavity Width** (Piece Part & Tooling Cost Driver)*Shortest dimension of part in the plane normal to the draw direction*User Required(≥ 0.100): mm***Cavity Height** (Piece Part & Tooling Cost Driver)*Dimension of part measured parallel to the draw direction*User Required(≥ 0.100): mm

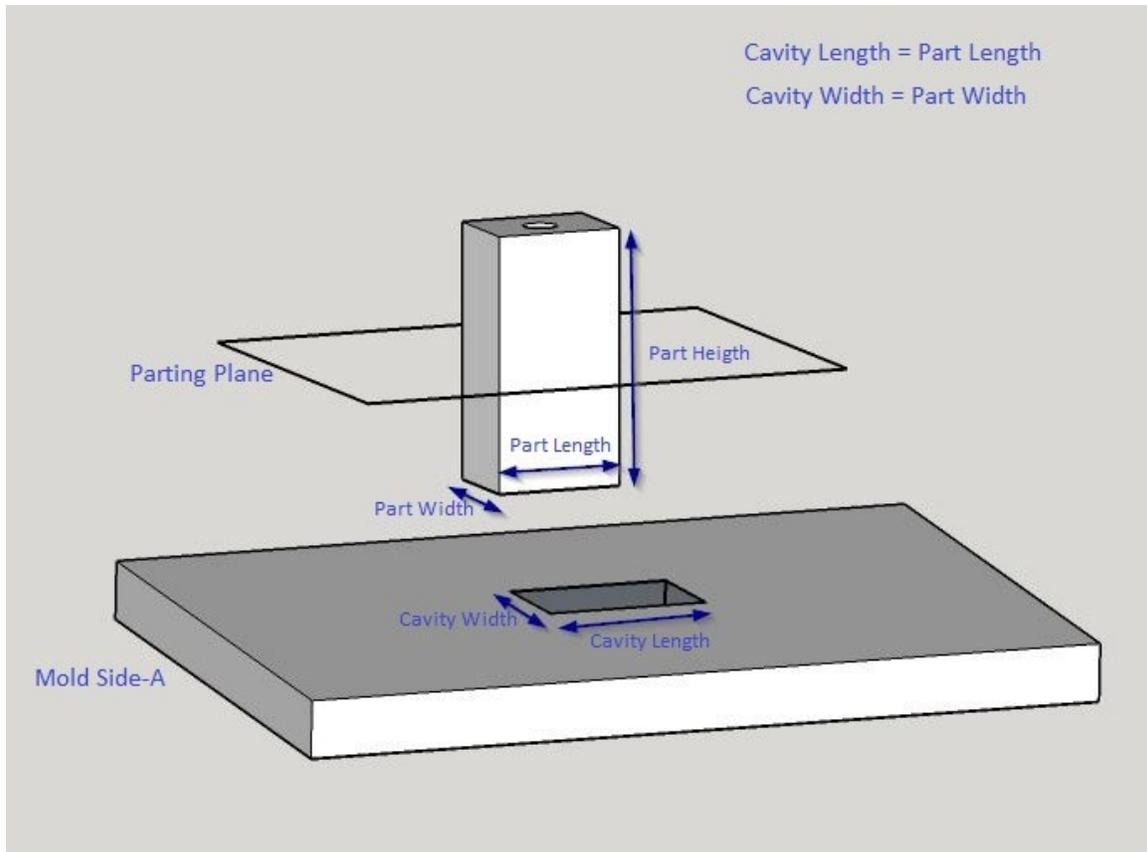
The following required PSOs are associated with the routing node **Plastic Molding PG**:

- **Cavity Height** (specifies both cavity height and part height)
- **Cavity Length** (specifies both cavity length and part length)
- **Cavity Width** (specifies both cavity width and part width)

You must supply values for these inputs, which serve two general purposes:

- To specify part dimensions, that is, the length, width, and height of the part's bounding box. Part length and width are used to determine runner volume and runner area. Runner volume and area contribute to piece part cost via material utilization (see [Material Utilization](#)), injection time (see [Times](#)), and required clamp force (see [Required Clamp Force](#)).
- To specify mold cavity dimensions, that is, the length, width, and height of the cavity's bounding box. These values help determine mold dimensions (see [Mold Dimensions](#)) and tooling costs (see [Tooling Cost](#)).

For injection molding cost models, part length and part width are defined so as to have the same values as cavity length and cavity width. So which part dimension is considered the height depends on how the part will be oriented in the mold—see the illustration below. (Note that this is different from process groups that do not involve a parting line; for those process groups, part length \geq part width \geq part height.)



Part Surface Area, Projected Area and Perimeter, and Wall Thickness

*Part Projected Area (Piece Part & Tooling Cost Driver)

The area of the part 'shadow' created by shining a light held parallel to the draw direction

Enter projected area(≥ 0.100): mm²

*Part Projected Perimeter (Tooling Cost Driver)

Length of the internal and external perimeter of the part 'shadow' created by shining a light held parallel to the draw direction

User Required(≥ 1.000): mm

*Average Part Thickness (Piece Part Cost Driver)

The surface area weighted average thickness (commonly called nominal thickness)

User Required(≥ 0.010): mm

*Max Part Thickness (Piece Part Cost Driver)

The diameter of the maximum sized sphere that can fit inside the part surface

User Required(≥ 0.010): mm

*Part Surface Area (Tooling Cost Driver)

The total part surface area. This includes both the top and bottom of the part

User Required(≥ 1.000): mm²

The following required PSOs are associated with the routing node **IM Routing**:

- **Part Projected Area:** area of the projection of the part onto a plane normal to the draw direction. Contributes to required clamp force (see [Required Clamp Force](#)) which affects machine selection and piece part cost.
- **Part Projected Perimeter:** perimeter of the projection of the part onto a plane normal to the draw direction. Affects tooling costs (see [Tooling Cost](#)).
- **Average Part Thickness:** average thickness of the walls of the part. Contributes to nominal wall thickness (see [Nominal Wall Thickness](#)) which affects cool time, required clamp force, machine selection, and piece part cost.
- **Max Part Thickness:** maximum thickness of the walls of the part. Contributes to nominal wall thickness (see [Nominal Wall Thickness](#)) which affects cool time, required clamp force, machine selection, and piece part cost.
- **Part Surface Area:** affects tooling costs (see [Tooling Cost](#)).

Undercut Depths

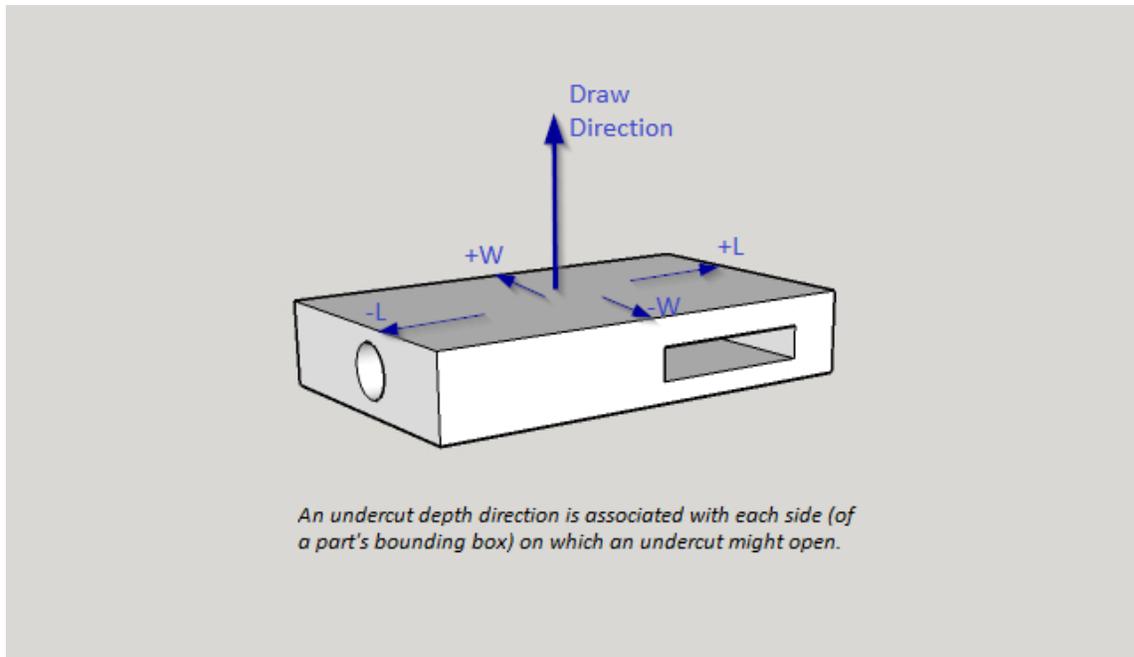
Undercut Depth in +L (Tooling Cost Driver)*Maximum depth of holes and undercuts looking in from the positive part length direction*User Override(>=0.000): mm**Undercut Depth in -L (Tooling Cost Driver)***Maximum depth of holes and undercuts looking in from the negative part length direction*User Override(>=0.000): mm**Undercut Depth in +W (Tooling Cost Driver)***Maximum depth of holes and undercuts looking in from the positive part Width direction*User Override(>=0.000): mm**Undercut Depth in -W (Tooling Cost Driver)***Maximum depth of holes and undercuts looking in from the negative part Width direction*User Override(>=0.000): mm

The user guided IM cost model uses four undercut depth values in order to estimate costs associated with slides. (The GCD-driven injection molding model, in contrast, analyzes the geometry of each undercut and determines how many slides are required and which undercuts each slide handles.)

You must enter this information by using the PSOs described below, which are associated with the routing node **Injection Molding**.

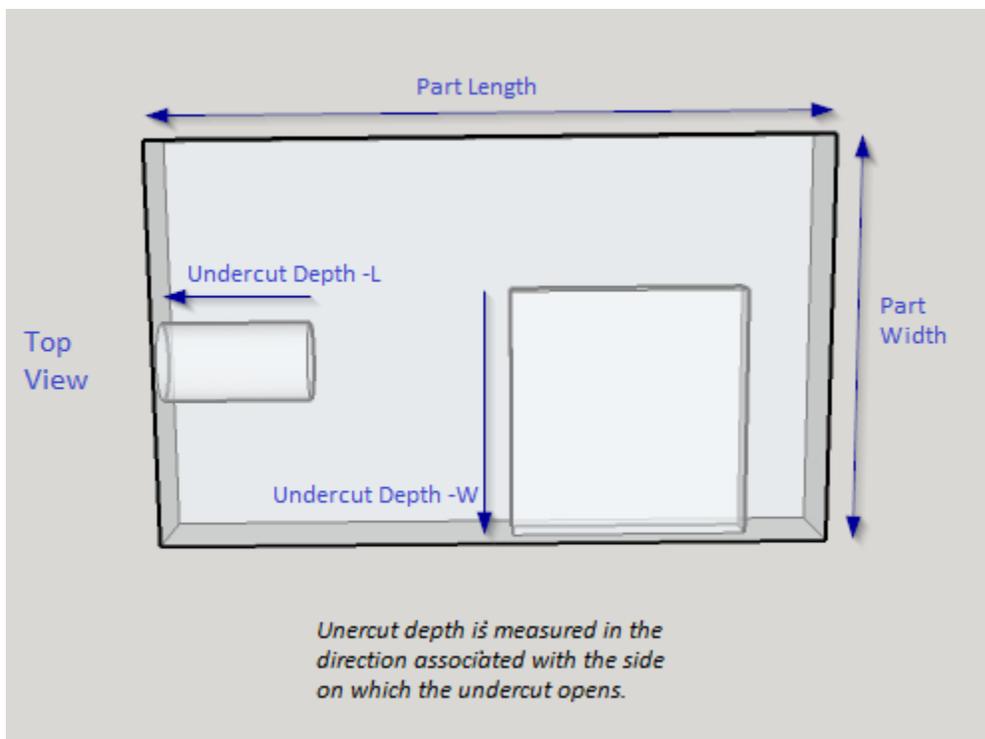
Each of the four inputs corresponds to one of the four walls of your part's bounding box. These four walls are the sides of the bounding box that enclose the part about parting line, in other words, the sides on which an undercut might open. Each side has an associated direction, the direction from which an undercut on that side would be accessible, that is, the direction from which a slide for the undercut would approach. The directions are named for a coordinate system whose axes run along the part's length and width (see [Part Length, Width, and Height](#)):

- +L and -L run lengthwise.
- +W and -W run widthwise.



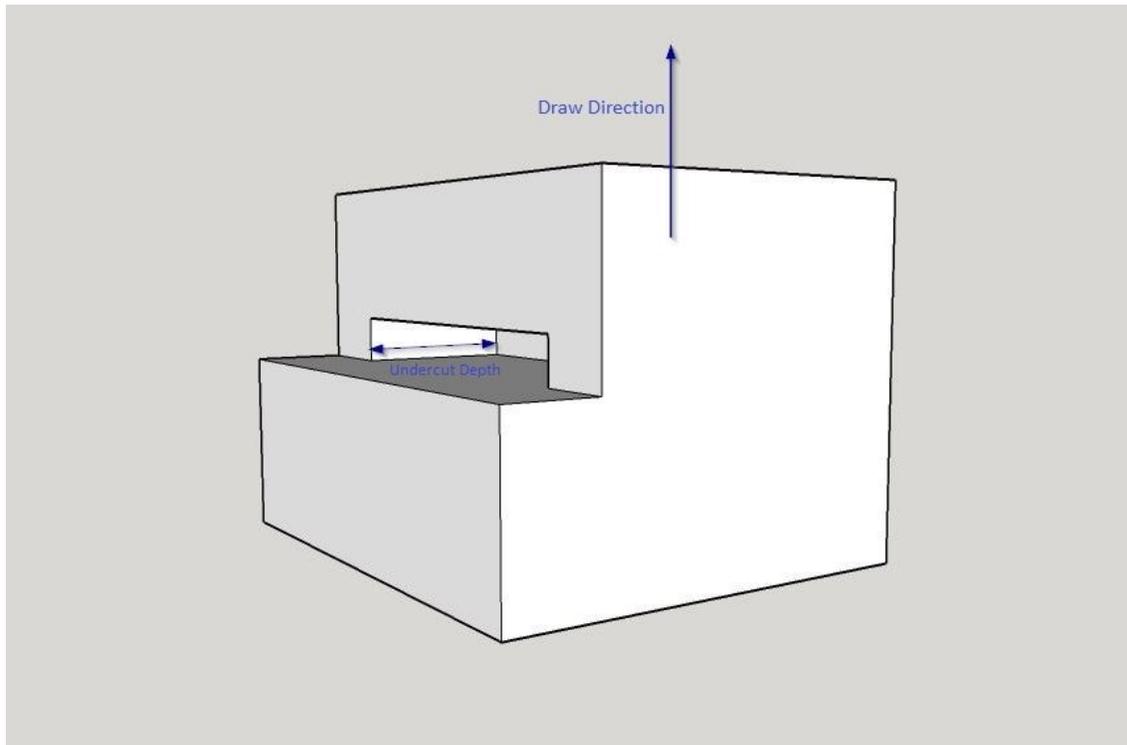
There is an undercut depth PSO for each of these directions:

- Undercut Depth in +L
- Undercut Depth in -L
- Undercut Depth in +W
- Undercut Depth in -W



Undercut depth for a particular side is the distance from the deepest point of the deepest undercut on that side. The depth is measured to the first point that is accessible from the

draw direction, in other words, the edge of the shadow that would be cast by a light projected from the draw direction.



Mold size increases as undercut depth increases. Note that the increase in mold size is significantly greater than the undercut depth, since a slide mechanism is considerably larger than the largest undercut it handles—see [Mold Dimensions](#) for more information.

Number of Lifters, Inserts and Unscrewing Mechanism

With the PSOs listed below, the user can specify the number of lifters, inserts, and unscrewing mechanisms to be included in the cost estimate. These values contribute to tooling costs. (The GCD-driven injection molding model, in contrast, analyzes part geometry to determine the quantity and size of any required actions.)

These PSOs are associated with the routing node **Injection Molding**:

- **Number of Lifters**
- **Number of Rib Inserts**
- **Number of Grill Inserts**
- **Number of Unscrewing Mechanisms** (to relieve threads)

The cost model estimates the size of each of these types of action based on part dimensions.

Note that slides are handled differently—see [Undercut Depths](#).

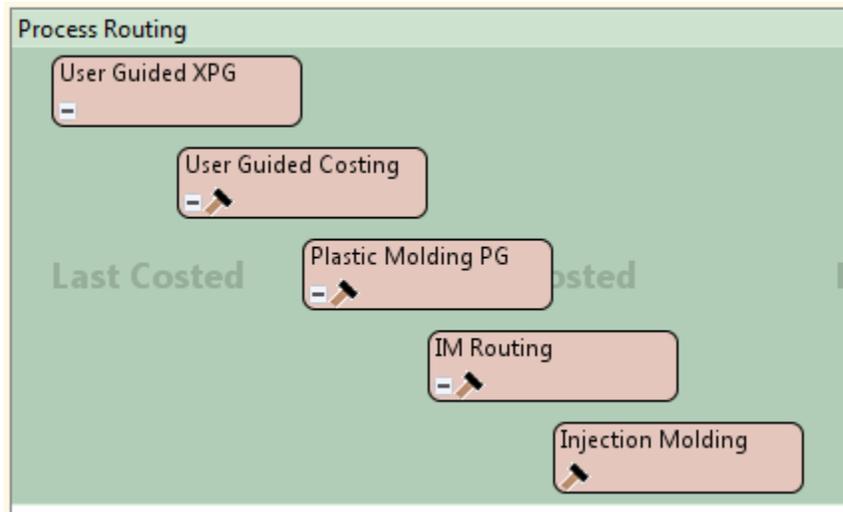
Feasibility and Routing

When you choose the **Plastic Molding** process group, aPiori selects process-level routings, operation-level routings, as well as machines and materials. These procedures are described in the following sections:

- Process-level Feasibility and Routing
- Machine Feasibility and Selection

Process-level Feasibility and Routing

aPiori uses only one process level routing rule for User Guided IM, which checks the compatibility of the process with the material under consideration.



You can also manually select one or both of the following optional, secondary processes:

- **Surface Treatment**, which includes the following processes:
 - Shot Blast
 - Degrease
 - Painting Processes
 - Electroplating
 - Labeling
- **Other Secondary Processes (Packaging)**, including the following processes:
 - Carton Forming
 - Pack and Load
 - Carton Sealing

Machine Feasibility and Selection

If aPiori is configured to automatically select a machine, it selects the machine with the lowest clamp force that satisfies all the feasibility rules.

The feasibility rules require all the following:

- The mold required for the part can fit on the machine.

- The clamp force required for the part can be achieved by the machine.
- The shot size required for the part can be provided by the machine.

More specifically, a machine is feasible only if all the following are true:

- Machine clamp force is greater than or equal to the required force.
- Machine maximum shot size (**Shot Size** property) is greater than or equal to the required shot size.
- Horizontal machine tie bar distance is greater than or equal the horizontal dimension of the mold base.
- Vertical machine tie bar distance is greater than or equal to the vertical dimension of the mold base.
- Machine maximum mold height is greater than or equal to the mold base height.

aPriori calculates the mold dimensions, clamp force, and shot size required for a given part based on a number of factors, including the number of cavities in the mold. The number of cavities defaults to one, but can be specified in **Process Setup Options** or calculated by aPriori. Calculation of required shot size, required clamp force, and number of cavities is described in more detail in [Required Shot Size](#), [Required Clamp Force](#), and [Number of Mold Cavities](#), and [Mold Dimensions](#).

To manually select a machine for a given process, select **Edit > Routing Selection** in the Manufacturing Process pane, right-click on the process in the Routing Selection window, and select **Machine Selection** from the context menu (see also [Selecting a machine for an operation in Manufacturing Process Information](#)).

Cost Algorithms and Calculations

Total injection molding costs aggregate the costs of material, labor, equipment, and tooling. Typically, tooling accounts for a significant portion of the total cost. The part's wall thickness and material (because they affect cooling time) have a significant impact on both labor and tooling costs.

This section details how costs are calculated by aPriori. Note that you can override the calculation of some of the quantities involved, and specify them explicitly—see [Additional User Inputs](#), below.

When not otherwise specified, costs are per part.

This section is organized into the following cost categories:

- Primary Direct Costs
- Other Direct Costs
- Material Utilization
- Times
- Nominal Wall Thickness
- Required Clamp Force
- Number of Mold Cavities
- Mold Dimensions
- Tooling Cost

Primary Direct Costs

Material cost and direct overhead cost are calculated using the formulas below.

$$\text{Material Cost} = (\text{Part Volume} * \text{Material Cost Per Volume} / \text{Utilization}) / \text{Final Yield}$$

aPiori calculates the cost for material based on the following factors:

- Part volume (specified by required PSO—see Part Volume)
- Material cost per volume (see formula below)
- Material utilization rate (see [Material Utilization](#))
- Final yield (see [Yields](#))

$$\text{Material Cost Per Volume} = \text{Material Cost Per Mass} * \text{Material Density}$$

Material cost per volume is the product of the following quantities:

- Material cost per mass (specified in the **Material Selection** dialog)
- Material density (listed in the **Material Selection** dialog)

$$\text{Labor Cost} = \text{Labor Rate} * \text{Labor Time} / \text{Final Yield}$$

Labor cost is the product of the following:

- Labor rate
- Labor time (see [Times](#) below)
- Final yield (see [Yields](#))

Other Direct Costs

$$\text{Additional Direct Costs} = \text{Colorant Cost} * \text{Part Rough Mass} / \text{Final Yield}$$

Additional direct costs are the product of the following:

- Colorant cost (default rate of 0, user-specified rate, or standard rate—see [Additional User Inputs](#))
- Part rough mass (see [Material Utilization](#), below)
- Final yield (see [Yields](#))

$$\text{Amortized Batch Setup} = \text{Startup Scrap Cost Per Part} + (\text{Setup Time per Batch} * (\text{Labor Rate} + \text{Direct Overhead Rate})) / \text{Batch Size}$$

Amortized batch setup, setup cost per part, depends on the following:

- Startup scrap cost per part (see formula below)
- Setup time per batch (specified by a machine property)
- Labor rate (specified by the machine property **Labor Rate**)
- Direct overhead rate (see [Direct and Indirect Overhead](#))
- Batch size (specified in the **Production Scenario** screen of the Cost Guide)

$$\text{Startup Scrap Cost Per Part} = (\text{Sum of Per Part Material, Labor, and Overhead Cost}) * \text{Number of Scrap Parts}$$

Startup scrap cost per part is a function of the following:

- Per part material cost
- Labor cost (see [Primary Direct Costs](#))

- Overhead cost (see [Direct and Indirect Overhead](#))
- Number of scrap parts (see formula below)

Number of Scrap Parts = Default Scrap Time / Cycle Time

Number of scrap parts is the quotient of the following:

- Default scrap time (specified in a cost model variable, `scrapTimeInMinutes_IM`)
- Cycle time (see [Times](#) below)

Total Production Volume = Part Annual Volume * Part Production Life

Total production volume is the product of the following:

- Part annual volume (specified in the **Production Info** dialog)
- Part production life volume (specified in the **Production Info** dialog)

Yields

Final Yield = Final Output Volume / Input Volume

Final yield affects material, labor, and overhead costs per part. It is the fraction of parts created by this process in the current production scenario that will survive as good parts once any secondary processes are completed. That is, final yield is the fraction of parts created by this process that are *not* discarded as scrap parts, either by this process or by a downstream process. Final yield depends on the following:

- Final Output Volume (product of the annual volume and number of production years, specified in the Production Scenario screen of the Cost Guide)
- Input volume (see the formula below). This is the total number of parts produced by this process, including all parts discarded as scrap from this process or downstream processes.

Input Volume = Local Output Volume + Number of Scrap Parts for This Process

Input volume is the total number of parts produced by this process in the current scenario, including all parts discarded as scrap from this process or downstream processes. It is the sum of the following:

- Local output volume (see the formula below). This is the number of parts produced by this process, excluding parts discarded as scrap by this process, but including parts that are discarded as scrap by downstream processes.
- Number of scrap parts for this process (see the formula below)

Local Output Volume = Final Output Volume + Number of Scrap Parts Downstream

Local output volume is the number of parts produced by this process in the current scenario, excluding parts discarded as scrap by this process, but including parts that are discarded as scrap by downstream processes. It is the sum of the following:

- Final output volume (product of volume and number of production years, specified in the Production Scenario screen of the Cost Guide)
- Number of Scrap Parts Downstream. This is the number of parts discarded as scrap by downstream processes.

**Number of Scrap Parts for This Process =
(Local Output Volume / Good Part Yield) – Local Output Volume**

Number of scrap parts for this process is the number of parts produced by this process in the current scenario that are discarded as scrap by this process, before any downstream process is performed on them. It is a function of the following:

- Local output volume (see the formula above)
- Good part yield (specified by the machine property **Good Part Yield**). This is the fraction of parts produced by this process that are not discarded as scrap by this process but may be discarded as scrap by downstream processes.

Material Utilization

Material costs and utilization are determined with the help of the following formulas:

Part Rough Mass = Part Finish Mass / Utilization

Rough mass is the quotient of the following:

- Finish mass (see formula below)
- Utilization (see formula below)

Utilization = (1 – Material Waste Factor) * Mold Efficiency

Utilization depends on the following:

- Material waste factor (see formula below)
- Mold efficiency (machine property, typically 0.95)

Part Finish Mass = Part Volume * Material Density

Finish mass is the product of the following:

- Part volume (obtained from required PSO—see [Part Volume](#))
- Material density (listed in the **Material Selection** dialog)

Material Waste Factor = Runner Factor – Regrind Allowance

Material waste percentage is the difference between the following:

- Runner factor (see below)
- Regrind allowance (default of 0.25 specified in cost model variables or user-specified value—see [Additional User Inputs](#))

Runner factor is a function of the following:

- Runner volume (see below)
- Number of cavities (see [Number of Mold Cavities](#) above)
- Part volume (obtained from required PSO—see [Part Volume](#))

**runnerVolume = Number of Cavities *
(Part Length + Part Width) * π * ((Nominal Wall Thickness + 1.5)/2)²**

Runner volume is a function of the following:

- Number of cavities (see [Number of Mold Cavities](#) below)
- Part length and width (obtained from cavity dimensions—see [Part Length, Width, and Height](#))
- Nominal wall thickness (see [Nominal Wall Thickness](#))

Times

Times such as labor time and cycle time are calculated as described below.

Labor Time = Cycle Time x Number of Operators

Labor time is the product of the following:

- Cycle time (see formula below)
- Number of operators (specified by machine property, typically 0.5)

Cycle Time = (Injection Time + Cool Time + Ejection Time) / Number of Cavities

Cycle time is computed by default, but can be specified by the user—see [Additional User Inputs](#). If calculated, it is a function of the following:

- Injection time (see formula below)
- Cool time (see formula below)
- Ejection time (see formula below)
- Number of cavities (see [Number of Mold Cavities](#))

This value is adjusted by multiplying by the cost model variable `cycleTimeAdjustmentFactor` (which defaults to 1—see [Process Defaults and Thresholds](#)).

Injection Time = ((Number of Cavities x Part Volume) + Runner Volume) / Adjusted Injection Rate

Injection time is function of the following:

- Number of cavities (see [Number of Mold Cavities](#))
- Part volume (obtained from GCD extraction)
- Runner volume (see [Material Utilization](#))
- Adjusted injection rate (see formula below)

Adjusted Injection Rate = Injection Rate x 0.25

Adjusted injection rate is one quarter of the injection rate of the machine.

Cool Time = $0 - ((\text{Nominal Wall Thickness}^2) / (2 \times \pi \times \text{Material Thermal Diffusivity}) \times \ln(\pi/4) \times (\text{Eject Deflection Temperature} - \text{Mold Temperature}) / (\text{Melting Temperature} - \text{Mold Temperature}))$

Cool time is a function of the following:

- Nominal wall thickness (see [Nominal Wall Thickness](#))
- Material properties (listed in the **Material Selection** dialog):
 - Thermal diffusivity
 - Eject deflection temperature (temperature at which the part can be ejected from the mold without deformation)
 - Melting temperature
 - Mold temperature (required temperature of the mold to support proper molten polymer flow)

Ejection Time = Dry Cycle Time of Machine x 1.5

Ejection time is 50% greater than the machine dry cycle time.

Nominal Wall Thickness

Nominal wall thickness is calculated by default, but can be specified by the user (0.10-15.00 millimeters)—see [Additional User Inputs](#). If calculated, the following formula is used:

$$\text{Nominal Wall Thickness} = (2 * \text{Average Wall Thickness} + \text{Maximum Wall Thickness}) * 1.25/3$$

Nominal wall thickness is a linear combination of the following:

- Part average wall thickness (obtained from required PSO—see [Part Surface Area, Projected Area and Perimeter, and Wall Thickness](#))
- Part maximum wall thickness (obtained from required PSO—see [Part Surface Area, Projected Area and Perimeter, and Wall Thickness](#))

Required Shot Size

Required shot size affects machine selection (see [Machine Feasibility and Selection](#)). It is calculated with the following formula:

$$\text{Required Shot Size} = (\text{Shot Size Safety Factor} * \text{Part Volume} * \text{Number of Mold Cavities} * \text{Polystyrene Density}) / 1000000$$

Required shot size is the product of the following:

- Shot size safety factor (specified by the cost model variable `shotSizeSafetyFactor`)
- Part volume (obtained from required PSO—see [Part Volume](#))
- Number of cavities (see [Number of Mold Cavities](#))
- Polystyrene density (specified by the cost model variable `densityPolystyreneForShotSize`)

Required Clamp Force

Required clamp force affects machine selection (see [Machine Feasibility and Selection](#)) and tooling costs (including costs associated with mold borders and tryout time). It is calculated with the following formula:

$$\text{Required Clamp Force} = ((\text{Part Projected Area} * \text{Number of Cavities}) + \text{Runner Area}) * \text{Material Clamp Force} * \text{Clamp Safety Factor} / 1000$$

Required clamp force depends on the following factors:

- Part projected area (obtained from required PSO—see [Part Surface Area, Projected Area and Perimeter, and Wall Thickness](#))
- Number of cavities (see [Number of Mold Cavities](#))
- Runner area (see formula below)
- Clamping force associated with the material
- Clamp safety factor

$$\text{Runner Area} = \text{Number of Cavities} * (\text{Part Length} + \text{Part Width}) * (\text{Nominal Wall Thickness} + 1.5)$$

Runner area depends on the following:

- Number of cavities (see [Number of Mold Cavities](#))
- Part dimensions (obtained from cavity dimensions—see [Part Length, Width, and Height](#))
- Nominal wall thickness (see [Nominal Wall Thickness](#))

Number of Mold Cavities

The number of mold cavities defaults to 1. The user can override the default and specify the number (1-256)—see [Additional User Inputs](#).

The user can also direct aPiori to calculate the number of cavities in the cavity layout with the smallest perimeter that can accommodate the number of cavities required to produce the required annual volume (specified by the user in the Cost Guide).

The screenshot shows the 'Cost Guide' dialog box with three tabs: '1 Production Scenario', '2 GCD Tolerances', and '3 Process and Machine Options'. The 'Production Scenario' tab is active. Below the tabs is a dropdown menu for 'Recently used production settings'. The main content is divided into sections: '1.1 Basic Options' and '1.2 Company-Defined Attributes'. Under '1.1 Basic Options', there are fields for 'Process Group' (User Guided), 'VPE' (aPiori USA UG Plastic Molding), 'Process Routing' (with checkboxes for 'aPiori-computed routing' and 'optional process overrides'), 'Material' (ABS), and 'Volume and Batch Size'. The 'Volume and Batch Size' section is highlighted with a red box and contains the text '5,500 annually for 5.00 yrs' and a checkbox for 'in batches of aPiori-computed (458)'. Under '1.2 Company-Defined Attributes', there is a 'Description' field with the text 'foo bar'.

Calculation of the *required* number of cavities assumes round-the-clock production and depends on the following:

- Required annual volume
- Plant efficiency
- Injection/cool/ejection time (estimated as 1.2 times the cool time—see [Times](#) above)

Mold Dimensions

Estimates for mold dimensions are a factor in both machine selection and tooling cost estimates.

The mold dimension estimates are based on the following factors:

- Cavity dimensions (see [Part Length, Width, and Height](#))
- Undercut depth information (see [Undercut Depths](#))
- Clamp force used (see [Required Clamp Force](#))
- Number of mold cavities (see [Number of Mold Cavities](#))

**Mold Length = Cavity Length * Lengthwise Number of Cavities +
Mold Border on -L Side +
Mold Border on +L Side +
Lengthwise Gap between Cavities * (Lengthwise Number of Cavities - 1)**

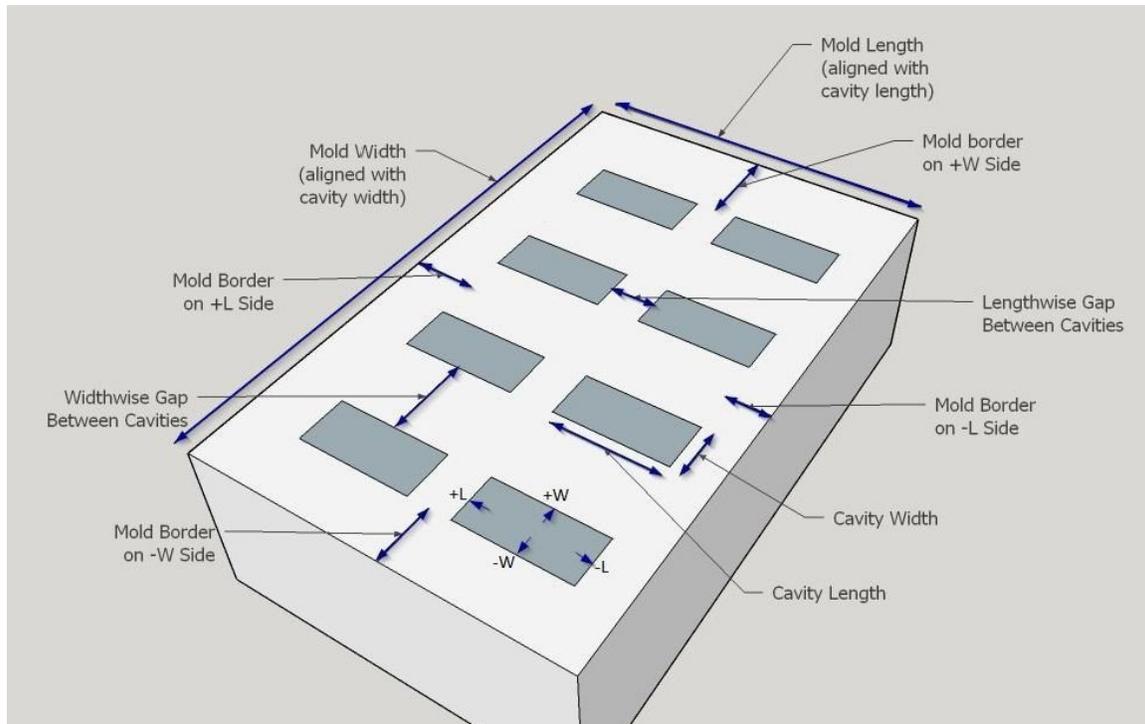
Mold length is the sum of the following:

- Cavity length * lengthwise number of cavities (see [Part Length, Width, and Height](#) and [Number of Mold Cavities](#))
- Mold border on the -L side (see [Mold Borders](#))
- Mold border on the +L side (see [Mold Borders](#))
- Lengthwise gap between cavities * (lengthwise number of cavities - 1) (see [Gaps between Cavities](#))

**Mold Length = Cavity Length * Lengthwise Number of Cavities +
Mold Border on -L Side +
Mold Border on +L Side +
Lengthwise Gap between Cavities * (Lengthwise Number of Cavities - 1)**

Mold width is the sum of the following:

- Cavity width * widthwise number of cavities
- Mold border on the -W side (see [Mold Borders](#))
- Mold border on the +W side (see [Mold Borders](#))
- Widthwise gap between cavities * (widthwise number of cavities - 1) (see [Gaps between Cavities](#))



Mold Borders

Each of the following considerations imposes a minimum size on mold borders:

- **Clamp force:** the border must be large enough to withstand the required clamp force (see [Required Clamp Force](#)). As the clamp force increases, the minimum border size increases. aPriori looks up the minimum border size by clamp force in `tblMoldBorderXDirection` (for the $-L$ and $+L$ borders) and `tblMoldBorderYDirection` (for the $-W$ and $+W$ borders).
- **Slides:** the border on a given side must be large enough to accommodate any slides that might be present on that side of the cavities (see [Undercut Depths](#)). As the specified undercut depth for that side increases, the minimum border size increases. Note that the increase in mold size is significantly greater than the undercut depth, since a slide mechanism is considerably larger than the largest undercut it handles. See [Slide Lengths](#) for more information.

The cost model estimates the border size as the larger of these two minima. That is, the cost model uses either the border size required by the clamp force or the border size required by the slides, whichever is larger.

Gaps between Cavities

Each of the following considerations imposes a minimum size on the gaps between two cavities:

- **Clamp force:** gaps must be large enough to withstand the required clamp force (see [Required Clamp Force](#)). As the clamp force increases, the minimum gap size increases. aPriori looks up the minimum gap size by clamp force in `tblSlidelessGapBetweenCavities`.

- Slides: the gap between two cavities must be large enough to accommodate any slides that might be present on the cavity sides that flank the gap (see [Undercut Depths](#)).

The lengthwise gap between two cavities must accommodate any slides on the +L side of one of the cavities as well as any slide on the –L side of the other cavity.

The widthwise gap between two cavities must accommodate any slides on the +W side of one of the cavities as well as any slide on the –W side of the other cavity.

As the specified undercut depth for that side increases, the minimum border size increases. Note that the increase in mold size is significantly greater than the undercut depth, since a slide mechanism is considerably larger than the largest undercut it handles. See [Slide Lengths](#) for more information.

The cost model estimates the gap size as the larger of these two minima. That is, the cost model uses either the gap size required by the clamp force or the gap size required by the slides, whichever is larger.

Slide Lengths

Slide lengths contribute to mold size (see [Mold Dimensions](#)).

Slide Length = Undercut Depth + (Multiple * Part Height) + Slide Clearance

Slide length is the sum of the following:

- Undercut depth (see [Undercut Depths](#))
- Multiple of part height (see [Part Length, Width, and Height](#))
- Slide clearance

**Multiple = {
1.5 if Part Height <= 152.4mm;
2 otherwise}**

Multiple is one of the following:

- 1.5 (if part height is less than or equal to 152.4mm)
- 2 (otherwise)

**Slide Clearance = {
5.0mm, if Number of Cavities == 1;
12.7mm otherwise}**

Slide clearance is one of the following:

- 5.0mm (for single-cavity molds)
- 12.7mm (for multi-cavity molds)

Tooling Cost

Tooling cost appears as **Hard Tooling** Cost in the cost taxonomy under Capital Costs.

Tooling cost depends on factors in the following areas:

- **Mold Material Costs**

- Purchased Mold Component Costs
- Tooling Labor Costs
- Miscellaneous Tooling Costs

Mold Material Costs

Following are material costs whose values are specified in toolshop:

- Core and cavity plate material type and rate
- Ejector box material type and rate
- Actions material type and rate
- EDM carbon

Purchased Mold Component Costs

Costs for the following purchased mold components are listed in the loop table `tblPurchasedItems`:

- Leader Pins Shoulder Bushings
- Return Pins Shoulder Bushings
- Ejector Guide Pins Bushings
- Locating Rings
- Sprue Bushing
- Stop Pins
- Side Locks
- Socket Head Cap Screws Short
- Socket Head Cap Screws Long
- Support Pillars
- Sleeve Pins
- Limit Switches
- Ejector Pins
- Water Manifolds
- Water Manifold Fittings
- Water Hoses
- Quick Hose Disconnects
- Water Baffles

Standard Mold Base Cost

Standard mold base cost is a component of tooling cost.

Standard Mold Base Cost = (A * Mold Area² + B * Mold Area + C + Height Multiplier * Part Height) * Mold Base Material Multiplier * Region Multiplier * Ejector BoxMaterial Multiplier

The standard mold base cost is estimated from a curve fit based on the following:

- Mold area (length times width—see [Mold Dimensions](#))
- Part height (see [Part Length, Width, and Height](#))

A, B, C, and Height Multiplier in the formula above are derived from a curve fit using a large, diverse data set.

The value is adjusted using the following factors:

- Mold material (looked up in `tblStdMoldBaseMaterialMultiplier`)
- Ejector material (looked up in `tblStdMoldBaseEjectorBoxMaterialMultiplier`)
- Region (see the tool shop variable `regionMultiplier`)

Tooling Labor Costs

Labor rates for the following are specified in toolshop:

- Machining:
 - CNC machining time and EDM machining time per cavity/core, die block, and action/cam, etc.
 - Deep hole or gun drilling time for water cooling lines
- Assembly
- Design:
 - 3D CAD modeling, mold flow, etc.
 - NC programming time per cavity/core, die blocks, actions/cams, etc.
- Finishing/polishing
- Spotting
- Tryout
- CMM inspection

CNC Machining Versus EDM Burning

Some mold components are created with CNC machining only, some mold components are created with EDM burning only, and some mold components are created with a combination of CNC machining and EDM burning.

The cost model assumes the following:

- Only CNC machining is used to create the following components:
 - Mold cavity
 - Mold core
- Only EDM Burning is used to create sleeve pins.
- Both CNC machining and EDM burning are used to create the following components:
 - Speaker grill inserts
 - Rib inserts & insert pockets
 - Lifters & lifter pockets
 - Slides & slide pockets

Labor Costs for Mold Items Created with CNC Machining

Labor costs for CNC machining are based on CNC setup time and item machining time. Following are the mold items created by CNC machining, together with the factors that contribute to machining time:

Cavity & core machining time is the sum of the following

- Cavity & core volume * time per unit volume * number of cavities
- Part surface area * time per unit area * number of cavities
- Runoff area * time per unit area
- Speaker grill volume * time per unit volume * number of cavities
- Total insert volume * time per unit volume * number of cavities
- Total insert pocket volume * time per unit volume * number of cavities

Actions machining time is the sum of the following:

- Total lifter volume * time per unit volume * number of cavities
- Total slide volume * time per unit volume * number of cavities

Labor Costs for Mold Items Created with EDM Burning

Labor costs for EDM burning are based on electrode design time as well as CNC setup and machining time for electrodes.

Electrode design depends on the number of the following features:

- Grill inserts
- Side cores
- Lifters
- Rib inserts

CNC setup and machining time for the creation of electrodes is determined roughly as follows:

- Setup time is 0.25 hours per electrode. The number of electrodes is the sum of the following:
 - Total side cores * number of burns per side core
 - Total lifters * number of burns per lifter
 - Total inserts * number of burns per insert
 - Total sleeve pins * number of burns per sleeve pin
 - Total speaker grills * number of burns per speaker grill
- Machining time is 0.003 hours per electrode unit volume. The total electrode volume is determined roughly as follows:
 - Slide electrode volume * total side cores * number of burns per side core
 - Lifter electrode volume * total lifters * number of burns per lifter
 - Insert electrode volume * total inserts * number of burns per insert
 - Sleeve pin electrode volume * total sleeve pins * number of burns per sleeve pin
 - Speaker grill electrode volume * total speaker grills * number of burns per speaker grill

The cost model assumes one slide for each undercut depth specified by a PSO (for a maximum of 4—see [Undercut Depths](#)). The number of lifters, ribs, and grills is specified explicitly by PSOs (see [Additional User Inputs](#)).

The cost model assumes the following regarding the number of burns per feature:

- Side cores: 3 burns each
- Lifters: 2 burns each
- Inserts: 3 burns each
- Sleeve pins: 2 burns each
- Speaker grills: 3 burns each

Miscellaneous Tooling Costs

Costs for the following also affect tooling costs:

- Heat treatment (rate specified in toolshop. Multiplied by sum of weights for core plates, cavity plates, inserts, and actions.)
- Plating (Multipliers set for all other plating types in **tbIToolPlatingMultiplier**)
- Stress relief (default rate specified in toolshop)
- Texture (Multipliers set for all other textures in **tbITexturingMultiplier**)
- Freight (default rate specified in toolshop)
- Markup/profit (default rate specified in toolshop)

Additional User Inputs

The PSOs listed in this section are all optional. They are associated with the routing node Injection Molding. For important PSOs not listed in this section see [Geometric User Inputs](#).

The following affect overall cost:

- **Number of Cavities**
 - Default value of 1
 - Value derived from annual volume for single mold (see [Number of Mold Cavities](#))
 - User-defined value (1-256)
- **Colorant**: affects **Additional Direct Costs** in the cost taxonomy—see [Other Direct Costs](#). **Process Setup Options** provide the following alternatives:
 - No colorant (default)
 - Colorant at standard rate (0.75 USD/kg, specified as a cost model variable)
 - Colorant at user-defined color charge
- **Material Regrind Allowance**: affects material utilization--see [Material Utilization](#). **Process Setup Options** allow you to enter a cost per unit weight:
 - User-override
- **Cycle Time**: affects overall labor and overhead costs--see [Primary Direct Costs](#). **Process Setup Options** provide the following alternatives:
 - Value computed from nominal wall thickness (default— see [Nominal Wall Thickness](#))
 - User-defined value

The following values affect tooling costs (see [Tooling Cost](#)):

- **Number of Hot Drops** (per cavity)
 - Default value (0)
 - User-defined number of standard hot drops
 - User-defined number of Sequential Valve Gates (SVG) hot drops
- **Cavity Finish**
 - 300 stone
 - 600 stone (default)
 - 320 grit paper
 - 600 grit paper
 - SPI A-3
 - SPI A-2
 - SPI A-1
- **Number of Plates in Mold**
 - 2-plate mold
 - 3-plate mold
- **Parting Line Complexity**
 - Flat
 - Non-flat
- **Plating of the Mold**
 - None
 - Nickel
 - Nitride
 - Chrome
 - Teflon
 - Tribo-Coating
- **Cavity Texture**
 - None
 - Fine-shallow
 - Moderate-medium
 - Coarse-deep
- **Heat Treating of Mold**
 - Yes
 - No
- **Stress Relief Mold**
 - Yes
 - No
- **Mold Material** (core and cavity plates)
 - P20 Tool Steel
 - H13 Tool Steel
 - Stainless Steel
 - Carbon Steel

- Aluminum
- Epoxy
- **Material for the Actions**
 - P20 Tool Steel
 - H13 Tool Steel
 - Stainless Steel
 - Carbon Steel
 - Aluminum
- **Ejector Box Material**
 - P20 Tool Steel
 - H13 Tool Steel
 - Stainless Steel
 - Carbon Steel
 - Aluminum
- **EDM Electrode Material**
 - Carbon
 - Copper
- **Freight Rate**
 - Default VPE rate (toolshop variable)
 - User-defined value
- **Import Duty Rate**
 - Default VPE rate (toolshop variable)
 - User-defined value
- **SG&A Rate**
 - Default VPE percent (toolshop variable)
 - User-defined value
- **Markup and/or Profit Rate**
 - Default VPE rate (toolshop variable)
 - User-defined value

The following also affect tooling costs. For each of these, you can use **Process Setup Options** either to specify that the value is GCD-extracted or to supply a user-defined value.

- **Number of Lifters:** 0-128
- **Number of Unscrewing Mechanisms** (to relieve threads): 0-64
- **Number of Rib Inserts:** 0-64
- **Number of Grill Inserts:** 0-64

Process Defaults and Thresholds

The table below lists some of the important cost model variables, together with default values and descriptions.

Variable	Value	Unit Type	Units	Description
clampForceSafetyFactor	1.1			multiplier of clamp pressure required to insure that the machine is capable of applying the necessary mold pressure (10% safety factor)—see Required Clamp Force .
cycleTimeAdjustmentFactor	1			Factor used to globally increase or decrease cycle time evaluations per process. See Times .
defaultNumCavities	1			Default value for the number of cavities in one mold. User may override via Process Setup Options . See Number of Mold Cavities .
defaultNumHotDrops	0			
defaultRegrindAllowance	0.25			Default allowable percentage of runners and scrap allowed with virgin material—see Material Utilization .
defaultStandardMoldBaseMultiplier	0.6			Discount factor for using a standard mold rather than making a custom mold—see Standard Mold Base Cost .
laborRateAdjustmentFactor	1			Factor used to globally increase or decrease labor rate evaluations per process.
overheadRateAdjustmentFactor	1			Factor used to globally increase or decrease overhead time evaluations per process—see Direct and Indirect Overhead .
scrapTimeInMinutes_IM	15	min	minute	Initial setup time for Injection Molding where parts are assumed to be scrap—see Other Direct Costs .
shotSizeSafetyFactor	1.02			See Required Shot Size .
tryoutTimeLarge	24	hr	hour	Basic tryout for a large mold
tryoutTimeSmall	12	hr	hour	Basic tryout for a small mold
tryoutsWithTexture	4			Average number of times that the mold should be tested for textured parts



27 User Guided Sheet Metal—Progressive Die

This section describes the costing details and inputs that are available for User Guided Progressive Die. This process is part of the User Guided process group for UG Sheet Metal VPEs. See [User Guided Costing](#) for an introduction to user-guided costing.

For this process, aPriori estimates manufacturing times and costs for high-volume sheet metal parts. The routing can include secondary surface treatment and packaging processes (if you have licensed these modules). Since this is not a GCD-driven cost model, cost estimates are not based on a CAD model and geometry extraction; rather, basic geometric inputs (such as blank dimensions and number of bends and forms) are provided by the user. See [Sheet Metal](#) for the GCD-driven progressive die cost model.

The chapter includes the following sections:

- Cost Model Overview
 - Geometric Inputs
 - Feasibility and Routing
 - Cost Algorithms and Calculations
 - Additional User Inputs
 - Process Defaults and Thresholds
-

Cost Model Overview

With some notable differences, the user guided progressive die cost model is based on the same calculations as the GCD-driven cost model for progressive die found in the Sheet Metal process group.

An important difference between the user guided model and the GCD-driven model is that the latter assigns operations to individual GCDs, and then uses operation precedence and operation compatibility rules to assign operations to die stations. The user guided model, in contrast, uses geometric inputs (such as number of up bends, number of down bends, number of up forms, and number of down forms) to estimate the total number of die stations. Together with a calculated estimate of average die cost per die station, this allows the user guided model to determine tooling costs.

In general, costs are determined by aggregating material, labor, machine, and tooling costs.

This overview section summarizes assumptions and limitations of the following aspects of the model:

- General Process
- Part Geometry
- Materials
- Machines
- Tooling

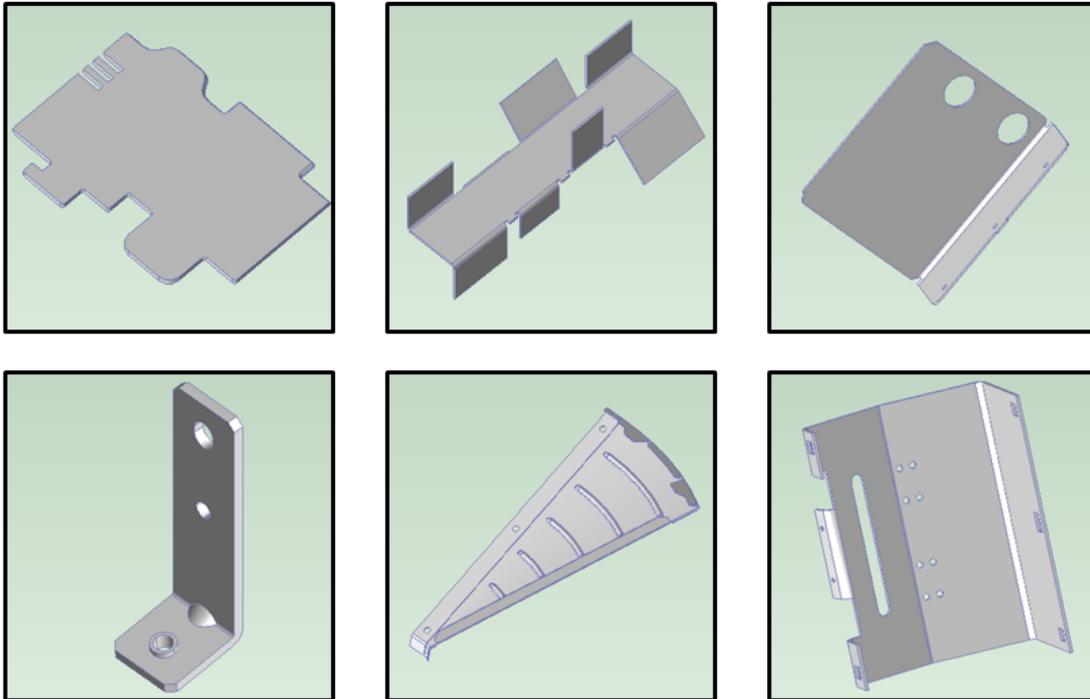
General Process

Progressive die is a high volume sheet metal manufacturing process in which coil stock is fed through a sequence of stations, each of which performs a set of operations. The combined effect of these operations results in the finished part.

If you have licensed the appropriate modules, your routing can include optional heat treatment, surface treatment, and packaging processes.

Part Geometry

A small selection of example parts is shown below.



Geometry extraction is replaced by geometric inputs in the user guided cost model. For progressive die, these inputs include, among others, the following:

- Part volume
- Flat pattern blank dimensions and perimeter
- Number of bends and forms
- Total hole perimeter and total form perimeter
- Total form depth and total bend length
- Number of undercut forms, bends over 95°, and groups of holes whose axes are not normal to the main surface.

See [Geometric Inputs](#) for more information.

Materials

Materials include the following:

- Aluminum: 3003, 5052, 6061
- Copper: 110
- Galvanized Steel: HR-1010, HR-1012, HR-1020
- Stainless Steel: 304, 316, 316L
- Steel: CR-1010, CR-1012, CR-1020, HR-1010, HR-1012, HR-1020

Material composition details include the following:

- Unit Cost (USD / kg)
- Density (kg / m³)
- Shear Strength (MPa)
- Ultimate Tensile Strength (MPa)

Material details include equivalent DIN and EN name standards for use with regional VPEs.

See [Material Selection](#) for more information.

Machines

The following tables list important machine property value ranges. Ranges are listed below for those processes that support a choice of machines:

Progressive Die Press

Property	Low End	High End
Press Force (kN)	658.0	9,964.0
Max Part Length (mm)	703.0	5,181.6
Max Part Width (mm)	701.04	2,590.8
Shut Height (mm)	330.0	1,372.0

See [Machine Selection](#) for more information.

Tooling

Total progressive die tooling cost can be specified with the PSO [Total Progressive Die Tooling Cost](#) or calculated as follows:

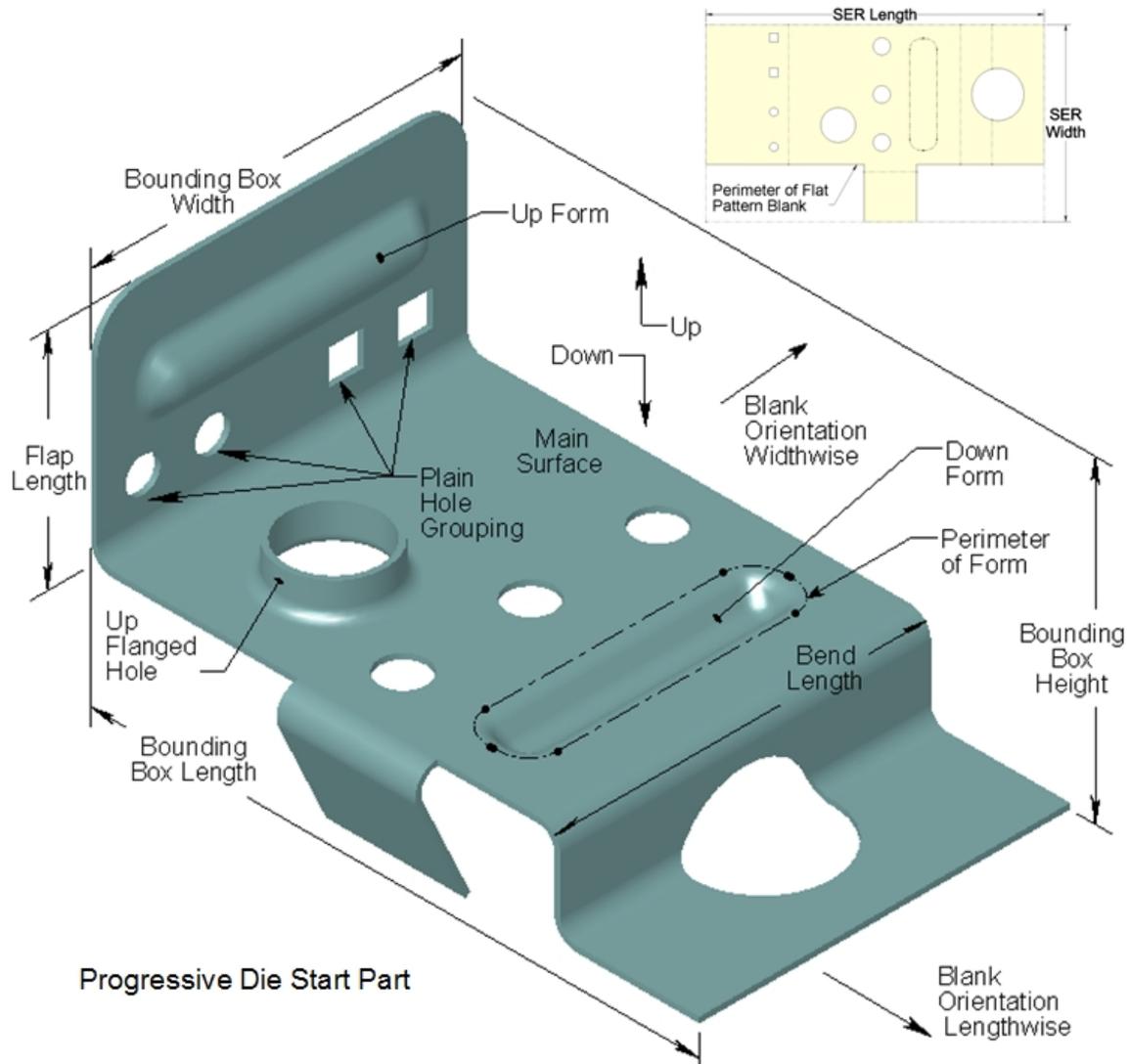
$$\text{Hard Tooling Cost} = \text{Number of Die Stations} * (\text{Average Material Cost per Die Station} + \text{Average Labor Cost per Die Station})$$

The values in this formula are estimated based on geometric inputs such as number of holes and forms, flat pattern blank area, and the number of holes, bends, and forms requiring side actions. See [Tooling Calculation](#) for more information.

Geometric Inputs

This section covers the Process Setup Options (PSOs) that serve as substitutes for the geometry extraction performed by GCD-driven cost models.

The following start part image provides an overview of the relevant, user-supplied, geometric values.



Follow these guidelines to ensure that your part will cost:

- 1 Create a virtual part and use the settings from an appropriate start part (select or search for the start part scenario from the **Recently Used Settings** menu of the Cost Guide's Production Scenario tab—see [Using Settings from a Start Part](#)).
- 2 Open the **User Guided** node in the Process and Machine Options tab of the Cost Guide. Supply a nonzero value for the required PSO [Part Volume](#).
- 3 Open the **Sheet Metal PG** node in the Process and Machine Options tab of the Cost Guide. Supply a nonzero value for all the following required PSOs:
 - [Thickness of Part](#)
 - [Length of the flat pattern's Smallest Enclosing Rectangle](#)
 - [Width of the flat pattern's Smallest Enclosing Rectangle](#)

Ensure that Length of the flat pattern's Smallest Enclosing Rectangle is greater than or equal to Width of the flat pattern's Smallest Enclosing Rectangle.

- 4 If your routing includes surface treatment or other secondary processes, supply nonzero values for all the following PSOs (the **Sheet Metal PG** node):
- o Length of the finished part's Bounding Box
 - o Width of the finished part's Bounding Box
 - o Height of the finished part's Bounding Box
- Ensure that Length of the finished part's Bounding Box is greater than or equal to Width of the finished part's Bounding Box, and that Width of the finished part's Bounding Box is greater than or equal to Height of the finished part's Bounding Box.
- 5 If your routing includes surface treatment, supply a non-zero value for the PSO **Part Surface Area** (in the **Sheet Metal PG** node).
- 6 Open the **Progressive Die Routing** node. Supply a non-zero value for **Perimeter of flat pattern blank**. Supply a value for all the other required PSOs; if you or your start part supplies a value greater than 0, also supply *consistent* values for the associated, *conditionally* required PSOs. Each required PSO's associated conditionally required PSOs are listed below, together with their consistency requirements.
- 7 Open the **Progressive Die** node. If you or your atrt part supplies values for the optional PSOs **Number of Flanged or Countersunk Holes** or **Number of Deep Draw Forms**, also supply *consistent* values for the associated, *conditionally* required PSOs. For these two optional PSOs, the associated conditionally required PSOs are listed below, together with their consistency requirements.

The following table lists the Progressive Die Routing node required PSO's. Any associated conditionally required PSOs are shown together with their consistency requirements:

Progressive Die Routing node Required PSO	Associated Conditionally Required PSO
▪ Perimeter of flat pattern blank	None
▪ Number of Holes	▪ Total Perimeter of Holes
▪ Number of Bends	▪ Total Length of Bends ▪ Number of UP Bends ▪ Number of DOWN Bends Ensure that total perimeter is nonzero and that the number of UP and DOWN bends sums to Number of Bends.
▪ Number of Forms	▪ Total Perimeter of Forms ▪ Total Depth of Forms ▪ Number of UP Forms ▪ Number of DOWN Forms Ensure that total perimeter is nonzero and that the number of UP and DOWN forms sums to Number of Forms.

The following table lists the Progressive Die node optional PSOs that have associated conditionally required PSOs. The associated conditionally required PSOs are shown together with their consistency requirements:

Progressive Die node Optional PSO	Associated Conditionally Required PSOs
<ul style="list-style-type: none"> Number of Flanged or Countersunk Holes 	<ul style="list-style-type: none"> Number of UP Flanged or Countersunk Holes Number of DOWN Flanged or Countersunk Holes <p>Ensure that these values sum to Number of Flanged or Countersunk Holes.</p>
<ul style="list-style-type: none"> Number of Deep Draw Forms 	<ul style="list-style-type: none"> Depth of Deepest Deep Draw Form <p>Ensure that this value is greater than 0.</p>

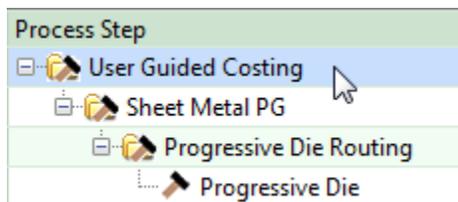
The Progressive Die node has several other important geometric PSOs. All the geometric PSOs are described in detail in the following sections:

- User Guided Costing Node
- Sheet Metal PG Node
- Progressive Die Routing Node
- Progressive Die Node

Non-geometric PSOs are described in [Additional User Inputs](#).

User Guided Costing Node

The top-level PSO node includes one PSO, which is required. If you do not supply a value for this PSO, the part fails to cost.



Part Volume

Required

Part volume is a required input for all user guided processes. This is the volume of the material that constitutes the part.

Part volume is used to calculate part mass. Part mass is used in material cost and utilization calculations—see [Material Cost and Utilization](#).

Part Volume (Piece Part & Tooling Cost Driver)Used to calculate part mass and various values impacting part and tooling cost*User Required(≥ 0.000): mm³

Enter a value greater than 0.

Sheet Metal PG Node

The Sheet Metal PG node includes PSOs that apply to all user guided sheet metal parts.



This node includes three required inputs related to the dimensions of the flattened blank:

- Thickness of Part
- Length of the flat pattern's Smallest Enclosing Rectangle
- Width of the flat pattern's Smallest Enclosing Rectangle

***Thickness of Part**
Enter the thickness of the metal used to make the part
 User Required(≥ 0.000): mm

***Length of the flat pattern's Smallest Enclosing Rectangle**
The SER is the smallest rectangle that completely encloses the flat pattern
 User Required(≥ 0.000): mm

***Width of the flat pattern's Smallest Enclosing Rectangle**
The SER is the smallest rectangle that completely encloses the flat pattern
 User Required(≥ 0.000): mm

This node also includes three conditionally required inputs, related to the part dimensions:

- Length of the finished part's Bounding Box
- Width of the finished part's Bounding Box
- Height of the finished part's Bounding Box

****Length of the finished part's Bounding Box**
Length is the longest dimension of the Bounding Box
 User Required(≥ 0.000): mm

****Width of the finished part's Bounding Box**
Width is the second longest dimension of the Bounding Box
 User Required(≥ 0.000): mm

****Height of the finished part's Bounding Box**
Height is the shortest dimension of the Bounding Box
 User Required(≥ 0.000): mm

Finally, there is a conditionally required PSO for surface area:

- Part Surface Area

****Surface Area of the Part**
Required if this scenario includes secondary processes
This drives the cost of secondary processes like plating, anodizing, powder coating, etc
 User Override(≥ 0.000): mm²

Thickness of Part

Required

This is the thickness of the stock used to create the part. This value contributes to material utilization via blank mass (see [Material Cost and Utilization](#)), and affects machine selection via required press force (see [Machine Selection](#)).

Enter a value greater than 0.

Length of the flat pattern's Smallest Enclosing Rectangle

Required

This is the longer dimension of the flattened part's smallest enclosing rectangle (that is, SER length > SER width). It contributes to material utilization (see [Material Cost and Utilization](#)) and tooling cost (see [Tooling Calculation](#)) and can contribute to cycle time (via material advance time, if the part's length is oriented in the pitch direction—see [Cycle Time Calculation](#)). It also affects machine selection via die dimensions (see [Machine Selection](#)).

Enter a value greater than 0.

Width of the flat pattern's Smallest Enclosing Rectangle

Required

This is the shorter dimension of the flattened part's smallest enclosing rectangle (that is, SER length > SER width). It contributes to material utilization (see [Material Cost and Utilization](#)) and tooling cost (see [Tooling Calculation](#)) and can contribute to cycle time (via material advance time, if the part's width is oriented in the pitch direction—see [Cycle Time Calculation](#)). It also affects machine selection via die dimensions (see [Machine Selection](#)).

Enter a value greater than 0.

Length of the finished part's Bounding Box

Conditionally required; may be required for secondary processes.

This is the longer dimension of the finished part's smallest enclosing box (that is, bounding box length > bounding box width). It may contribute to calculations for secondary processes. A value of 0 is used by default.

Enter a value greater than 0.

Width of the finished part's Bounding Box

Conditionally required; may be required for secondary processes.

This is the shortest dimension of the finished part's smallest enclosing box (that is, bounding box length > bounding box width). It may contribute to calculations for secondary processes. A value of 0 is used by default.

Enter a value greater than 0.

Height of the finished part's Bounding Box

Conditionally required; may be required for secondary processes.

This is the height of the finished part's bounding box—the dimension of the bounding box that is perpendicular to the flat pattern blank. It may contribute to calculations for secondary processes. A value of 0 is used by default.

Enter a value greater than 0.

Part Surface Area

Conditionally required; may be required for secondary processes.

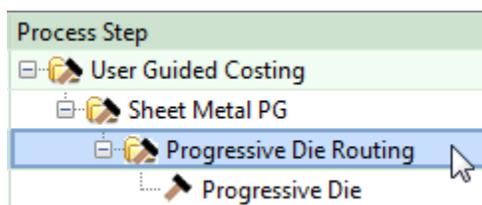
This is the surface area of the material comprising the finished part. It may contribute to calculations for secondary processes. A value of 0 is used by default.

Enter a value greater than 0.

Progressive Die Routing Node

The Progressive Die Routing node includes required and conditionally required PSOs. A conditionally required PSO is one that is required if you have entered a nonzero value for a particular, related PSO. For example, Total Perimeter of Holes is required if you have entered a nonzero value for Number of Holes.

If you don't enter a value for a required PSO, the part fails to cost. If you don't enter a value for a conditionally required PSO when its associated condition is met, the part fails to cost.



The following PSOs are required:

- Perimeter of flat pattern blank
- Number of Holes
- Number of Bends
- Number of Forms

The following PSOs are conditionally required:

- Total Perimeter of Holes
- Total Length of Bends
- Number of UP Bends
- Number of DOWN Bends
- Total Perimeter of Forms
- Total Depth of Forms
- Number of UP Forms
- Number of DOWN Forms

Perimeter of flat pattern blank

Required

This is the perimeter of the flattened part. It affects the number of trimming stations, which affects tooling costs (see [Tooling Calculation](#)). It also affects required press force, which affects machine selection (see [Machine Selection](#)).

Number of Holes

Required

This is the number of holes in the finished part. It affects the number of die stations, as well as tooling material and tooling labor costs per die station (see [Tooling Calculation](#)).

If you enter a value for this PSO, you must also enter a value for [Total Perimeter of Holes](#).

Enter a value greater than or equal to 0.

Total Perimeter of Holes

Conditionally required

You must enter a value for this PSO if you entered a nonzero value for Number of Holes. It is the sum of the perimeters of all holes. It affects required press force, which affects machine selection (see [Machine Selection](#)).

Enter a value greater than 0.

Number of Bends

Required

This is the number of bends that need to be created in order to make the part. It affects average labor hours per die station, average die material mass per die station, and number of die stations (see [Tooling Calculation](#)).

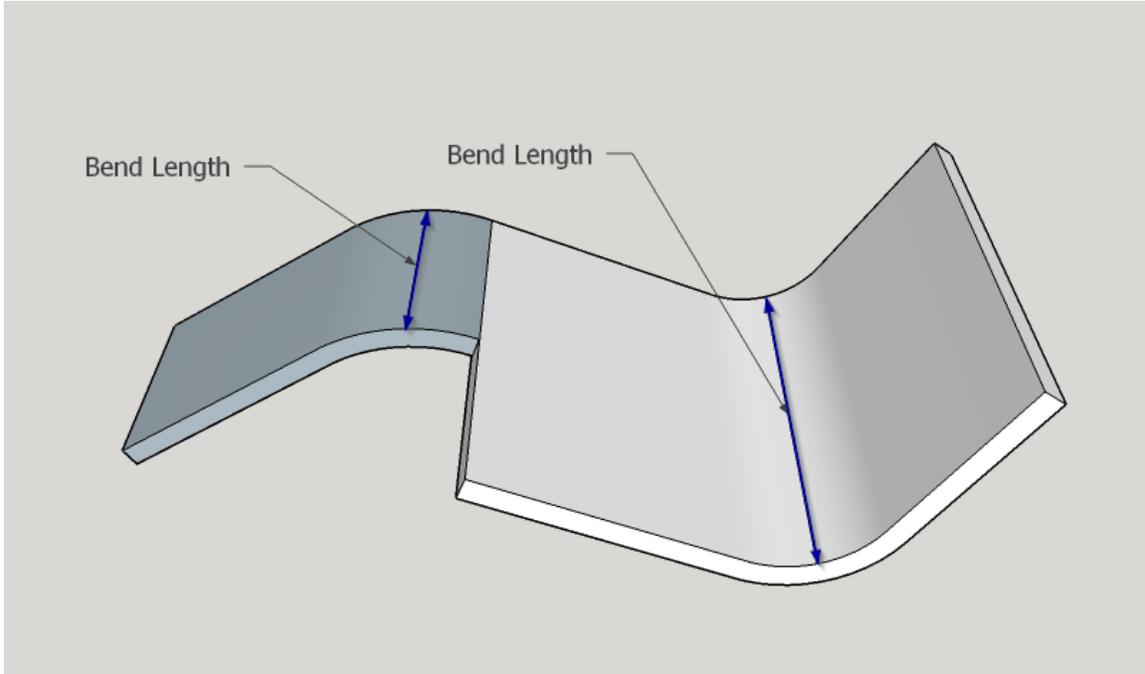
If you enter a value for this PSO, you must also enter a value for [Total Length of Bends](#), [Number of UP Bends](#), and [Number of DOWN Bends](#).

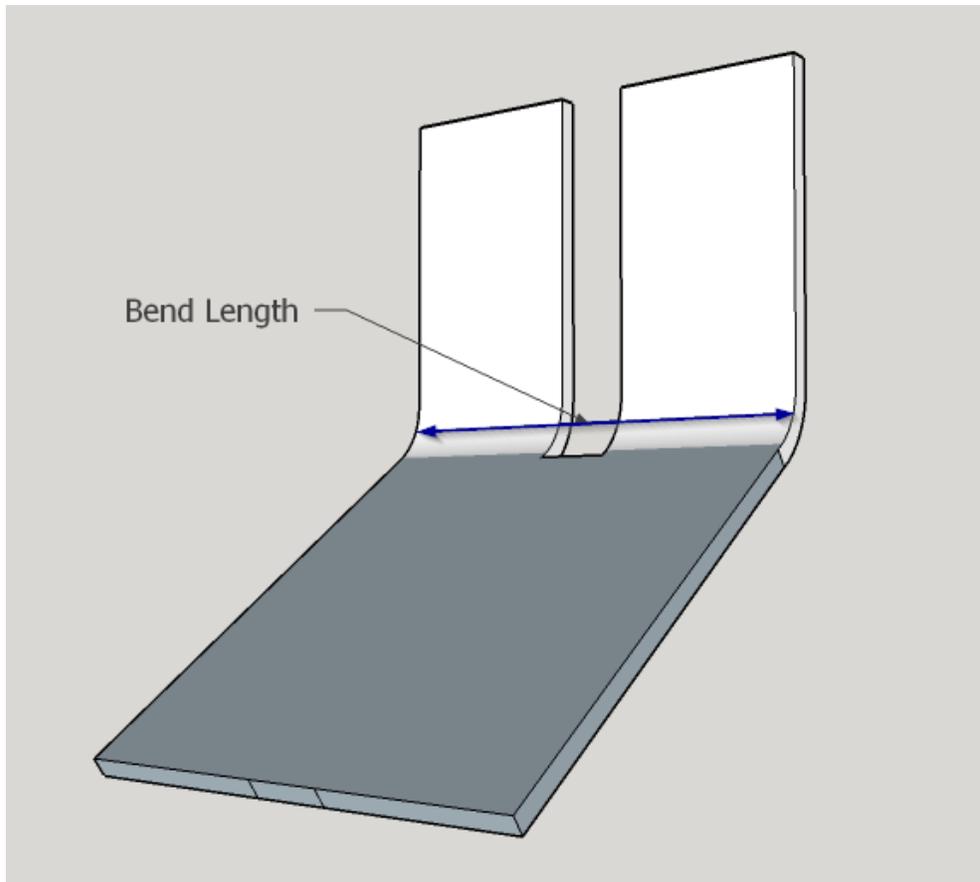
Enter a value greater than or equal to 0.

Total Length of Bends

Conditionally required

You must enter a value for this PSO if you entered a nonzero value for Number of Bends. It is the sum of the lengths of all bends. It contributes to required press force, which affects machine selection (see [Machine Selection](#)).





Enter a value greater than 0.

Number of UP Bends

Conditionally required

You must enter a value for this PSO if you entered a nonzero value for Number of Bends. This is the number of bends performed in the UP direction with respect to the part's main surface. It affects the number of die stations, which contributes to tooling costs (see [Tooling Calculation](#)).

Enter a value greater than or equal to 0.

Number of DOWN Bends

Conditionally required

You must enter a value for this PSO if you entered a nonzero value for Number of Bends. This is the number of bends performed in the DOWN direction with respect to the part's main surface. It affects the number of die stations, which contributes to tooling costs (see [Tooling Calculation](#)).

Enter a value greater than or equal to 0.

Number of Forms

Required

This is the number of forms that need to be created in order to make the part. It affects average labor hours per die station, average die material mass per die station, and number of die stations (see [Tooling Calculation](#)).

If you enter a value for this PSO, you must also enter a value for [Total Perimeter of Forms](#), [Total Depth of Forms](#), [Number of UP Forms](#), and [Number of DOWN Forms](#).

Enter a value greater than or equal to 0.

Total Perimeter of Forms

Conditionally required

You must enter a value for this PSO if you entered a nonzero value for Number of Forms. It is the sum of the perimeters of all forms. It contributes to required press force, which affects machine selection (see [Machine Selection](#)).

Enter a value greater than 0.

Total Depth of Forms

Conditionally required

You must enter a value for this PSO if you entered a nonzero value for Number of Forms. It is the sum of the depths of all forms. It contributes to the computed blank addendum width (see [Width of Addendum Added to Blank Size \[per side\]](#)).

Form depth is the distance from the surface containing the form to the form's farthest point. It is measured along a normal to the surface.

Enter a value greater than 0.

Number of UP Forms

Conditionally required

You must enter a value for this PSO if you entered a nonzero value for Number of Forms. This is the number of forms created in the UP direction with respect to the part's main surface. It affects the number of die stations, which contributes to tooling costs (see [Tooling Calculation](#)).

Enter a value greater than or equal to 0.

Number of DOWN Forms

Conditionally required

You must enter a value for this PSO if you entered a nonzero value for Number of Forms. This is the number of forms created in the DOWN direction with respect to the part's main surface. It affects the number of die stations, which contributes to tooling costs (see [Tooling Calculation](#)).

Enter a value greater than or equal to 0.

Progressive Die Node

This Progressive Die node includes optional PSOs, as well as some conditionally required PSOs.



This section lists the PSOs in this node that act as substitutes for the geometry extraction performed for GCD-driven process groups. Other PSOs associated with this node are listed in User Inputs.

The following PSOs are optional:

- Number of Plain Hole Groupings
- Number of Flanged or Countersunk Holes
- Number of Tapped Holes
- Number of Bends that Intersect with a Hole
- Number of Bends with Flap Length Over 75mm
- Number of Bends that are Greater than 95 Degrees
- Number of Forms with Depth Over 10mm
- Number of Undercut Forms
- Number of Deep Draw Forms
- Number of Non-IDLE Stations
- Average Progressive Die Tooling Labor Hours per Station
- Average Progressive Die Tooling Labor Rate
- Average Progressive Die Tooling Material Mass per Station
- Average Progressive Die Tooling Material Rate
- Total Progressive Die Tooling Cost

The following PSOs are conditionally required:

- Number of UP Flanged or Countersunk Holes
- Number of DOWN Flanged or Countersunk Holes
- Depth of Deepest Deep Draw Form

Number of Plain Hole Groupings

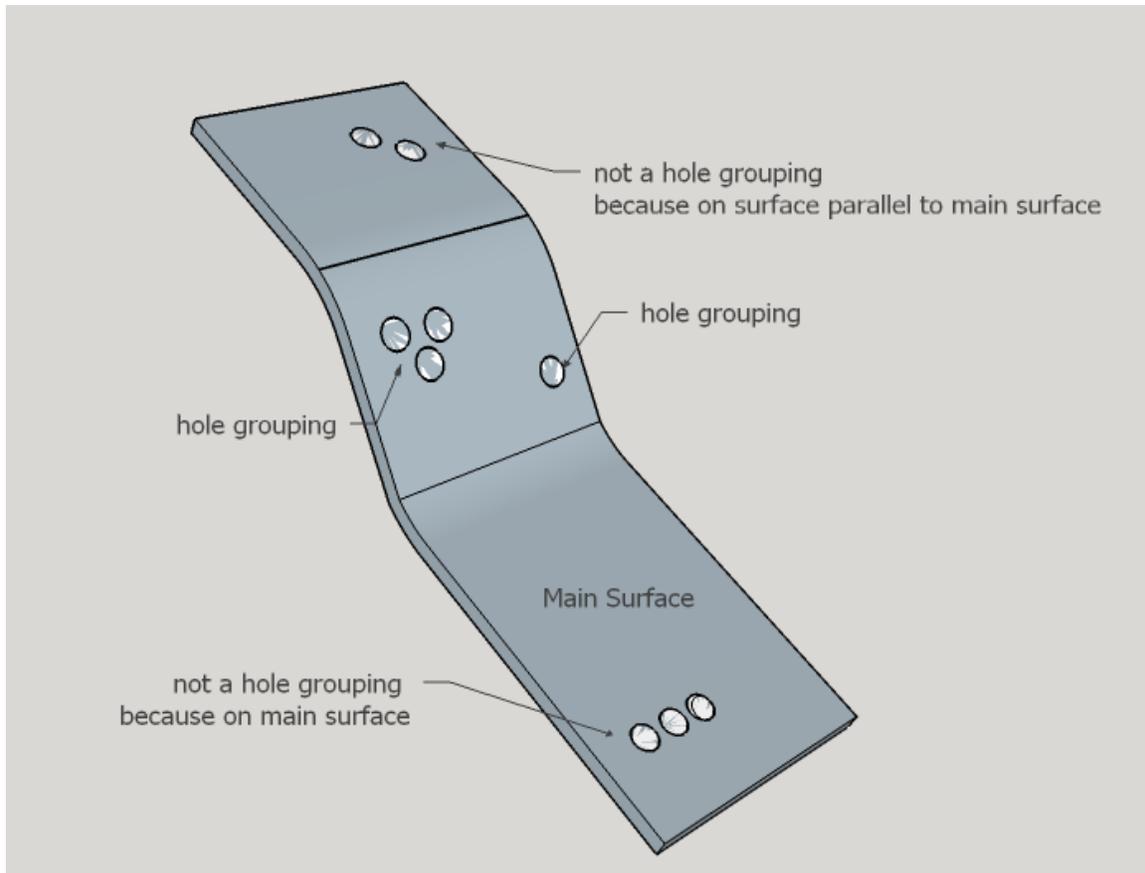
Optional

By default, the number of hole groups is assumed to be 0. You can override the default with this PSO.

A plain hole is one that is not countersunk, flanged, or threaded.

A hole grouping is a group of holes for which all the following hold:

- Not on a plane parallel with the mainSurface.
- Located in the same general area of the part.
- Have axes parallel that are all parallel to each other.



For the purposes of tooling calculations, the holes in a plain hole group are assumed to be handled by a dedicated cam piercing station—see [Tooling Calculation](#).

Feasible hole-group size and hole spacing depend on the cam unit's physical characteristics; the GCD-driven cost model lists physical characteristics of various cam piercing units in the lookup table **camUnitSizes**.

Number of Flanged or Countersunk Holes

Optional

By default, the number of flanged or countersunk holes is assumed to be 0. You can override the default with this PSO.

If you enter a value greater than 0 for this PSO, you must supply values for the PSOs [Number of UP Flanged or Countersunk Holes](#) and [Number of Flanged or Countersunk Holes](#).

Enter a value greater than or equal to 0.

Number of UP Flanged or Countersunk Holes

Conditionally Required

If you enter a value greater than 0 for Number of Flanged or Countersunk Holes, you must supply a value for this PSO. This is the number of holes that are flanged or countersunk in the UP direction with respect to the part's main surface. This value affects the number of die stations, which contributes to tooling costs (see [Tooling Calculation](#)).

Enter a value greater than or equal to 0.

Number of DOWN Flanged or Countersunk Holes

Conditionally Required

If you enter a value greater than 0 for Number of Flanged or Countersunk Holes, you must supply a value for this PSO. This is the number of holes that are flanged or countersunk in the DOWN direction with respect to the part's main surface. This value affects the number of die stations, which contributes to tooling costs (see [Tooling Calculation](#)).

Enter a value greater than or equal to 0.

Number of Tapped Holes

Optional

By default, the number of tapped holes is assumed to be 0. You can override the default with this PSO. The value determines the number of hole threading stations—see [Tooling Calculation](#).

Enter a value greater than or equal to 0.

Number of Bends that Intersect with a Hole

Optional

By default, the number of bends that intersect a hole is assumed to be 0. You can override the default with this PSO. The value affects the number of scoring stations—see [Tooling Calculation](#).

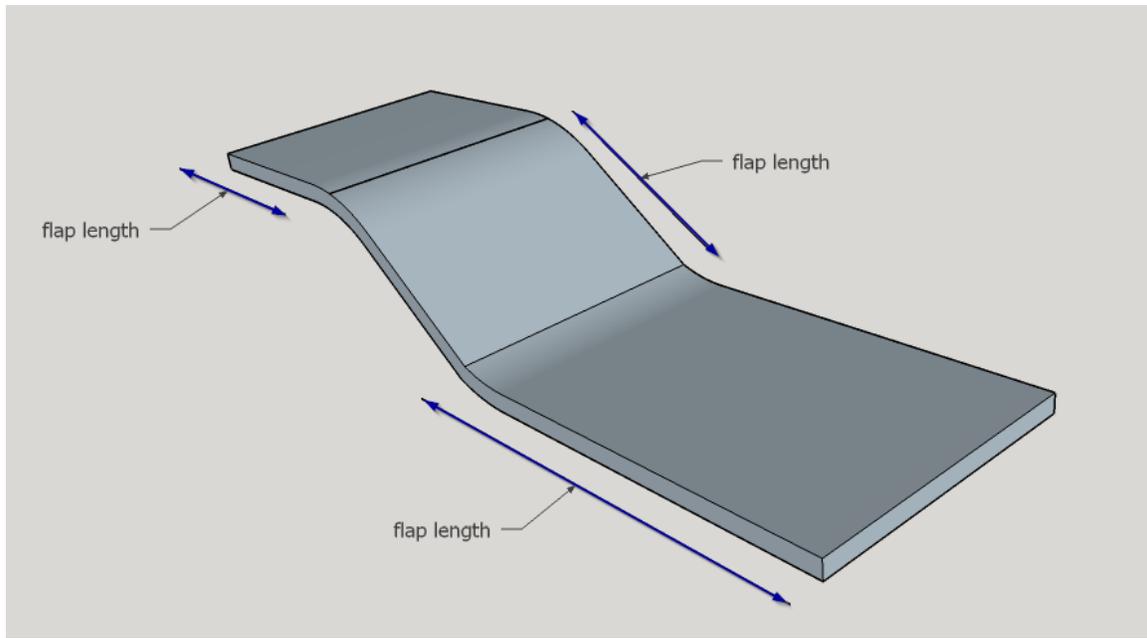
Enter a value greater than 0.

Number of Bends with Flap Length Over 75mm

Optional

By default, the number of bends with flap length over 75mm is assumed to be 0. You can override the default with this PSO. The value affects the number of restriking stations—see [Tooling Calculation](#).

Enter a value greater than or equal to 0.

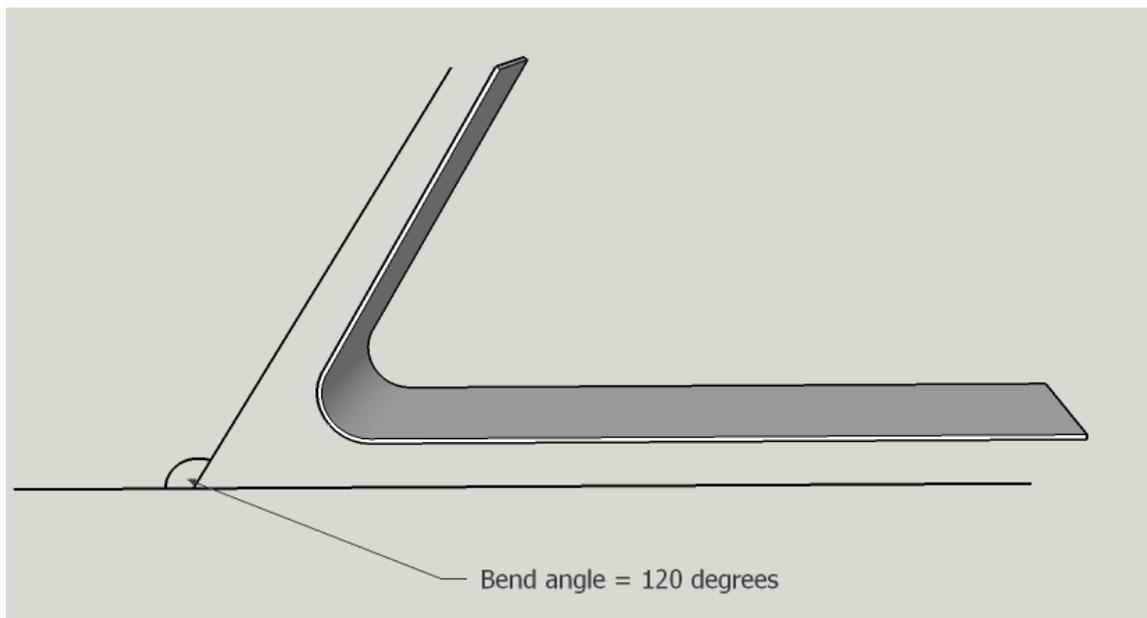


Number of Bends that are Greater than 95 Degrees

Optional

By default, the number of bends greater than 95 degrees is assumed to be 0. You can override the default with this PSO. The value determines the number of cam bending stations—see [Tooling Calculation](#)

Enter a value greater than or equal to 0.



Number of Forms with Depth Over 10mm

Optional

By default, the number of forms over 10mm high is assumed to be 0. You can override the default with this PSO. The value affects the number of restriking stations—see [Tooling Calculation](#).

Enter a value greater than or equal to 0.

Number of Undercut Forms

Optional

By default, the number of undercut forms is assumed to be 0. You can override the default with this PSO. *An undercut form is a form that is not on the part's main surface or on another surface that is parallel with the part's main surface.* The value determines the number of cam forming stations—see [Tooling Calculation](#).

Enter a value greater than or equal to 0.

Number of Deep Draw Forms

Optional

By default, the cost model assumes there are no deep draw forms, and, the deep draw time component of cycle time is 0 (see [Cycle Time Calculation](#)). A deep draw form has a depth-to-width ratio greater than 1, and has an area (length * width) greater than half the part area (part length * part width).

To include nonzero deep draw time, enter a nonzero value for this PSO, and a nonzero value for [Depth of Deepest Deep Draw Form](#).

Depth of Deepest Deep Draw Form

Conditionally required

If you entered a nonzero value for Number of Deep Draw Forms, you must a nonzero value for this PSO, which helps determine deep draw time (see [Cycle Time Calculation](#)).

Number of Non-IDLE Stations

Optional

By default, the number of active die stations required by the current part is calculated as described in [Tooling Calculation](#). You can override this value and specify the number of active stations explicitly with this PSO.

Enter a value greater than or equal to 0.

Average Progressive Die Tooling Labor Hours per Station

Optional

By default, the average time per die station of labor spent on the manufacture of tooling is calculated as described in [Tooling Calculation](#). You can override this value and specify labor hours explicitly with this PSO.

Enter a value greater than or equal to 0.

Average Progressive Die Tooling Labor Rate

Optional

By default, the average labor rate per die station for the manufacture of tooling is specified by the toolshop variable **avgLaborRate**. You can override this value and specify the labor rate explicitly with this PSO.

Enter a value greater than or equal to 0.

Average Progressive Die Tooling Material Mass per Station

Optional

By default, the average mass per die station of the tooling required for the current part is calculated as described in [Tooling Calculation](#). You can override this value and specify tooling mass explicitly with this PSO.

Enter a value greater than or equal to 0.

Average Progressive Die Tooling Material Rate

Optional

By default, the average per-die-station raw material cost per kilogram for tooling is specified by the toolshop variable **avgMatlRate**. You can override this value and specify the material rate explicitly with this PSO.

Enter a value greater than or equal to 0.

Total Progressive Die Tooling Cost

Optional

By default, the total cost of the manufacture of the tooling required for the current part is calculated as described in [Tooling Calculation](#). You can override this value and specify the total tooling cost explicitly with this PSO.

Enter a value greater than or equal to 0.

Feasibility and Routing

When you choose the **Sheet Metal** process group, aPriori selects process-level routings, as well as machines and materials. These procedures are described in the following sections:

- [Process-level Feasibility](#)
- [Material Selection](#)
- [Machine Selection](#)

Process-level Feasibility

Process feasibility depends on the values you supply for the geometric PSOs. The process is feasible only if all the following hold:

- You have supplied values for all required PSOs.
- You have supplied nonzero values for part volume, blank SER width, blank SER length, blank thickness, and part height.
- For each conditionally required PSO, you have supplied a nonzero value if and only if you have supplied a nonzero value for its associated PSO. For example,

- you have supplied a nonzero value for total bend length if and only if you have supplied a nonzero value for number of bends.
- If you supplied a value greater than 0 for number of bends, the values you supplied for number of UP bends and number of DOWN bends sum to the number of bends.
 - If you supplied a value greater than 0 for number of forms, the values you supplied for number of UP forms and number of DOWN forms sum to the number of forms.
 - If you supplied a value greater than 0 for number of flanged or countersunk holes, the values you supplied for number of UP flanged or countersunk holes and number of DOWN flanged or countersunk holes sum to the number of flanged or countersunk holes.
 - If your routing includes surface treatment or other secondary processes, you have supplied values for part bounding box length, part bounding box width, and part surface area.

For detailed information on all these PSOs, see [Geometric Inputs](#).

Material Selection

In direct integration mode with Pro/ENGINEER, if the composition selection mode is **MCAD**, aPriori selects the MCAD composition from the part, if available. Otherwise aPriori selects the VPE default material (Steel, CR-1020).

In CAD-independent mode, aPriori selects the VPE default material (Steel, CR-1020 in aPriori starting point VPEs).

In both direct integration and CAD-independent mode, you can use aPriori's selection or else manually select a material composition and override the material unit cost. To manually specify a material, select **Edit > Material Selection** in the Manufacturing Process pane (see also [Selecting material in Manufacturing Process Information](#)). You can override the unit cost if desired.

All material stock is virtual stock. Material Stock dimensions are given by the PSO [Thickness of Part](#) and the calculated or user-specified value for coil width (see [Material Cost and Utilization](#) and [Coil Width](#)).

Machine Selection

aPriori selects the default machine if it is feasible; otherwise, aPriori selects the feasible machine with the lowest overhead (specified by the sum of the machine properties **Direct Overhead Rate** and **Indirect Overhead Rate**).

The machine feasibility rules require that the machine can accommodate the following:

- [Die Length and Width](#)
- [Die Height](#)
- [Required Press Force](#)

Die Length and Width

Die must fit on the press table with a margin specified by the cost model variables **pressTableWidthMargin** and **pressTableLengthMargin**. Table dimensions are specified by the

machine properties **Press Table Width** and **Press Table Length**. Die width is the sum of the following:

- Coil width * station count (see [Material Cost and Utilization](#))
- Coil width (additional coil width to allow for stamping area)
- Die block width allowance (specified in the lookup table **toolingComponentAttributes**, 609.6mm in aPriori starting point VPEs)

Similarly, die length is the sum of the following:

- Coil pitch * station count (see [Material Cost and Utilization](#))
- Coil pitch (additional coil pitch to allow for stamping area)
- Die block length allowance (specified in the lookup table **toolingComponentAttributes**, 254mm in aPriori starting point VPEs)

Die Height

Die height must fit within the machine **Shut Height** with a margin (on both top and bottom) specified in the lookup table **toolingComponentAttributes** for **minParallelHeight** (76.2mm in aPriori starting point VPEs). Die height is the sum of the following:

- 2 * die shoe thickness. Die shoe thickness depends on coil width (see [Tooling Calculation](#)), and is specified in the lookup table **toolingComponentAttributes** as one of the following:
 - **dieShoeThicknessLarge** (101.6mm in aPriori starting point VPEs) if coil width is greater than cost model variable **upperCoilWidthThreshold**
 - **dieShoeThicknessMedium** (88.9mm in aPriori starting point VPEs) if coil width is between the cost model variables **upperCoilWidthThreshold** and **lowerCoilWidthThreshold**
 - **dieShoeThicknessSmall** (76.2mm in aPriori starting point VPEs) if coil width is less than or equal to **lowerCoilWidthThreshold**.
- Cost model variable **defaultPartSpacing** (25.4mm in aPriori starting point VPEs) plus 75% of part height (specified by the PSO [Height of the finished part's Bounding Box](#))
- Cost model variable **defaultDieSpacing** (101.6mm in aPriori starting point VPEs)

Required Press Force

Required press force must not exceed the machine property **Press Force** (which is specified in kilonewtons). Required press force in newtons is the sum of the following:

- Required shear force, which is the product of the following:
 - Blank perimeter (specified by the PSO [Perimeter of flat pattern blank](#)) plus total hole perimeter (specified by the PSO [Total Perimeter of Holes](#))
 - Blank thickness (specified by the PSO [Thickness of Part](#))
 - Material shear strength (specified by the material property **Shear Strength**).
- Required bending force, which is the product of the following:
 - Total bend length (specified by the PSO [Total Length of Bends](#))
 - Blank thickness (specified by the PSO [Thickness of Part](#))
 - Material property **Ultimate Tensile Strength**
- Required drawing force, which is the product of the following:
 - Total form perimeter (specified by the PSO [Total Perimeter of Forms](#))

- Blank thickness (specified by the PSO Thickness of Part)
- Material property **Tensile Yield Strength**
- Required total holding force, which is the sum of the following:
 - 5% of required shear force
 - 10% of Required bending force
 - 30% of Required drawing force

Cost Algorithms and Calculations

This section details how costs are calculated by aPriori. Note that you can override the calculation of many of the quantities involved, and specify them explicitly—see [User Inputs](#), below.

This section covers formulas in the following areas:

- Material Cost and Utilization
- Accounting Calculations
- Cycle Time Calculation
- Tooling Calculation

Material Cost and Utilization

Final Yield = Final Output Volume / Input Volume

Final yield affects material, labor, and overhead costs per part. It is the fraction of parts created by this process in the current production scenario that will survive as good parts once any secondary processes are completed. That is, final yield is the fraction of parts created by this process that are *not* discarded as scrap parts, either by this process or by a downstream process. Final yield depends on the following:

- Final Output Volume (product of the annual volume and number of production years, specified in the Production Scenario screen of the Cost Guide)
- Input volume (see the formula below). This is the total number of parts produced by this process, including all parts discarded as scrap from this process or downstream processes.

Input Volume = Local Output Volume + Number of Scrap Parts for This Process

Input volume is the total number of parts produced by this process in the current scenario, including all parts discarded as scrap from this process or downstream processes. It is the sum of the following:

- Local output volume (see the formula below). This is the number of parts produced by this process, excluding parts discarded as scrap by this process, but including parts that are discarded as scrap by downstream processes.
- Number of scrap parts for this process (see the formula below)

Local Output Volume = Final Output Volume + Number of Scrap Parts Downstream

Local output volume is the number of parts produced by this process in the current scenario, excluding parts discarded as scrap by this process, but including parts that are discarded as scrap by downstream processes. It is the sum of the following:

- Final output volume (product of volume and number of production years, specified in the Production Scenario screen of the Cost Guide)
- Number of Scrap Parts Downstream. This is the number of parts discarded as scrap by downstream processes.

Number of Scrap Parts for This Process = (Local Output Volume / Good Part Yield) – Local Output Volume

Number of scrap parts for this process is the number of parts produced by this process in the current scenario that are discarded as scrap by this process, before any downstream process is performed on them. It is a function of the following:

- Local output volume (see the formula above)
- Good part yield (specified by the machine property **Good Part Yield**). This is the fraction of parts produced by this process that are not discarded as scrap by this process but may be discarded as scrap by downstream processes.

Material Cost = ((Material Cost Per Mass * Custom Cut Multiplier * Part Mass) / Utilization) / Final Yield

aPriori calculates the cost for material based on the following factors:

- Material cost per mass (determined from **Material Stock** if stock is selected; otherwise, from **Material Composition** in the **Material Selection** dialog)
- Part mass (product of part volume and material density)
- Custom cost multiplier (specified by the cost model variable **customCutMultiplier**)
- Utilization (see formula below)
- Final Yield (see formula above)

Utilization = Part Mass / (Blank Mass / Number of Concurrent Parts)

Utilization depends on the following:

- Part mass (product of part volume and material density—see the **Part Volume** PSO and the **Density** property in the Materials table)
- Blank mass (see formula below)
- Number of concurrent parts (1 by default in aPriori starting point VPEs, but see **Number of Parts Stamped Concurrently**)

Blank Mass = Coil Pitch * Coil Width * Blank Thickness * Material Density

Blank mass is the product of the following:

- Coil pitch (calculated using the formula below or specified by a PSO—see **Coil Pitch**)
- Coil Width (calculated using the formula below or specified by a PSO—see **Coil Width**)
- Blank thickness (specified by the PSO **Thickness of Part**)
- Material density (specified by the **Density** property in the Materials table)

Coil Pitch = Blank SER Dimension + (2 * Addendum) + (2 * Edge Margin) + Center Carrier Strip Margin

Coil pitch depends on the following:

- Blank SER dimension (specified by the PSO **Width of the flat pattern's Smallest Enclosing Rectangle** if the blank XY orientation is widthwise--the default in aPriori starting point VPEs; specified by the PSO **Length** if the blank XY orientation is lengthwise. The XY orientation is specified by the cost model variable **defaultXyOrientation** or the PSO **Blank XY Orientation within Part Strip**)
- Addendum (0 by default or specified by the PSO **Width of Addendum Added to Blank Size [per side]**)
- Edge margin (specified by the cost model variable **defaultEdgeMargin** or the PSO **Trim Strip Applied to Length and Width of Part**)
- Center carrier strip margin (0 if carrier strip type is not center—see the PSO **Press Carrier Strip Type**; otherwise specified by the cost model variable **defaultPartStripSpacing** or the PSO **Pitch Margin Adder for Center Carrier Strip Type**)

Coil Width =

Number of Concurrent Parts * (Blank SER Dimension + (2 * Addendum) + (2 * Edge Margin)) + Carrier Strip Margin + French Stop Margin

Coil width depends on the following:

- Number of concurrent parts (1 by default or specified by the PSO [Number of Parts Stamped Concurrently](#))
- Blank SER dimension (specified by the PSO [Length](#) if the blank XY orientation is widthwise--the default in aPriori starting point VPEs; specified by the PSO [Width of the flat pattern's Smallest Enclosing Rectangle](#) if the blank XY orientation is lengthwise. The XY orientation is specified by the cost model variable [defaultXyOrientation](#) or the PSO [Thickness](#).)
- Addendum (0 by default or specified by the PSO [Width of Addendum Added to Blank Size \[per side\]](#))
- Edge margin (specified by the cost model variable [defaultEdgeMargin](#) or the PSO [Trim Strip Applied to Length and Width of Part](#))
- Carrier strip margin (0 if carrier strip type is center—see the PSO [Press Carrier Strip Type](#). If the carrier strip type is singleEdge, this is specified by the cost model variable [singleEdgeCarrierStripWidth](#) or the PSO [Single Edge Carrier Strip Width](#). If the carrier strip type is doubleEdge, this is double or—for two concurrent parts--triple the value specified by the cost model variable [doubleEdgeCarrierStripWidth](#) or the PSO [Double Edge Carrier Strip Width](#).)
- French stop margin (0 by default, or specified by the PSO [Press French Stop](#))

Note that this value is constrained by the minimum and maximum coil widths specified by the cost model variable [maximumStripWidth](#) and the PSOs [Maximum Strip Width](#) and [Minimum Strip Width](#). If the formula violates these constraints, the maximum or minimum coil width is used instead of the formula.

Accounting Calculations

Labor Cost = Labor Time * Labor Rate / Final Yield

Labor cost is a function of the following:

- Labor time (see formula below)
- Labor rate (specified by a machine property)
- Final yield (see the formula above)

Labor Time = Cycle Time * Labor Time Standard * Number of Operators

Labor time is the product of the following

- Cycle time (see the formula below)
- Labor time standard (specified as a machine property). This value reflects the amount of time spent by machine operators in between machine cycles, including time performing maintenance and cleaning tasks as well as time pausing between tasks. The amount is expressed as a cycle time multiplier.
- Number of operators (specified by the machine property **Number of Operators**)

$$\text{Amortized Batch Setup} = \frac{\text{Setup Time} * (\text{Labor Rate} + \text{Direct Overhead Rate})}{\text{Batch Size}}$$

Amortized batch setup depends on the following:

- Setup time per die station (specified as the machine property **Setup Time**)
- Labor rate (specified as a machine property)
- Direct overhead rate (see [Direct and Indirect Overhead](#))
- Batch size (specified in the **Production Scenario** screen of the Cost Guide)

Cycle Time Calculation

$$\text{Cycle Time} = \frac{\text{Press Cycle Time} + \text{Deep Draw Time} + \text{Material Advance Time}}{\text{Number of Concurrent Parts}}$$

Cycle time is a function of the following:

- Press cycle time (specified as a machine property)
- Deep draw time (based on depth of deepest drawn feature, and cost model variable **drawRate**)
- Material advance time (increases with coil pitch—see the formula above; interpolated from values looked up by coil pitch in the lookup table **pressMaterialAdvanceRate**)
- Number of concurrent parts (1 by default, or specified by the process setup option **Number of Parts Stamped Concurrently**)

The lookup table **pressMaterialAdvanceRate** lists advance rates (in strokes per minute) by part length.

Tooling Calculation

Total progressive die tooling cost can be specified with the PSO [Total Progressive Die Tooling Cost](#)

or calculated as described below.

$$\text{Hard Tooling Cost} = \text{Number of Die Stations} * (\text{Average Material Cost per Die Station} + \text{Average Labor Cost per Die Station})$$

Hard tooling cost depends on the following

- Number of die stations (specified by the PSO [Number of Non-IDLE Stations](#), or calculated by using the formula below)
- Material cost per die station (see the formula below)
- Labor cost per die station (see the formula below)

$$\text{Average Material Cost per Die Station} = \text{Average Material Mass per Die Station} * \text{Average Material Rate}$$

Average material cost per die station is the product of the following:

- Average material mass per die station (calculated as described below, or specified by the PSO [Average Progressive Die Tooling Material Mass per Station](#))
- Average material rate (specified by the PSO [Average Progressive Die Tooling Material Rate](#) or the toolshop variable **avgMatlRate**).

Average Material Mass per Die Station

Average material mass per active die station is estimated as a linear combination of

- Blank SER area
- Total number of holes
- Total number of bends and forms

aPriori chooses from among various sets of coefficients to be used in the linear combination based on the following:

- Number of concurrent parts (see the [PSO Number of Parts Stamped Concurrently](#))
- Whether the part requires side actions (that is, whether there are cam piercing, cam bending, or cam forming stations--see the formulas below)

The sets of coefficients are derived from large, representative data sets of sample of parts. (The material mass of IDLE stations is amortized over the active stations.)

Average Labor Cost per Die Station = Average Labor Hours per Die Station * Average Labor Rate

Average labor cost per die station is the product of the following:

- Average labor hours per die station (calculated as described below, or specified by the [PSO Average Progressive Die Tooling Labor Hours per Station](#))
- Average labor rate (specified by the [PSO Average Progressive Die Tooling Labor Rate](#) or the toolshop variable `avgLaborRate`).

Average Labor Hours per Die Station

Average labor hours per die station is estimated as a linear combination of

- Blank SER area
- Total number of holes
- Total number of bends and forms

aPriori chooses from among various sets of coefficients to be used in the linear combination based on the following:

- Number of concurrent parts (see the [PSO Number of Parts Stamped Concurrently](#))
- Whether the part requires side actions (that is, whether there are cam piercing, cam bending, or cam forming stations--see the formulas below)

The sets of coefficients are derived from large, representative data sets of sample of parts.

Number of Die Stations =
Number of Piloting Stations +
Number of Edge Trimming Stations +
Number of Trimming Stations +
Number of Piercing Stations +
Number of Cam Piercing Stations +
Number of Extruding or Countersinking Stations +
Number of Threading Stations +
Number of Scoring Stations +
Number of Bending Up Stations +
Number of Bending Down Stations +
Number of Cam Bending Stations +
Number of Forming Up Stations +
Number of Forming Down Stations +
Number of Cam Forming Stations +
Number of Restriking Stations +
Number of Cutoff Stations

The number of active die stations is the sum of the number of each of the types of dies station—see below.

Number of Piloting Stations = 1

The number of piloting stations is always 1.

Number of Edge Trimming Stations = 1

The number of edge trimming stations is always 1.

Number of Trimming Stations = rounddown(Blank Perimeter / Trim Punch Length)

–

Number of Edge Trimming Stations + Trim Station Adder for Two Out

The number of trimming stations depends on the following:

- Blank perimeter length (see the PSO [Perimeter](#))
- Trim punch length (see the formula below)
- Number of edge trimming stations (this is always 1—see above)
- Trim station adder for two out (1 if the number of concurrent parts is 2; 0 otherwise)

Trim Punch Length = {
typical large trim punch length, for large parts;
typical small trim punch length, for small parts;
Blank Perimeter/2, for very small parts}

Large and small trim punch lengths are 406.4 or 355.6 in aPiori starting point VPEs. They are specified in the lookup table **toolingComponentAttributes**.

Part size (large, small or very small) is determined as follows:

- Large, if blank perimeter (see the PSO [Perimeter](#)) is greater than the cost model variable **upperBlankPerimeterLengthThreshold**.
- Small, if the blank perimeter is between the cost model variables **upperBlankPerimeterLengthThreshold** and **lowerBlankPerimeterLengthThreshold** (but not equal to the lower threshold).

- Very small, if the blank perimeter is less than or equal to the cost model variable `lowerBlankPerimeterLengthThreshold`.

Number of Hole Piercing Stations = {1 if there are holes and either bends or forms; 0 otherwise}

The number of hole piercing stations is 1 if the part has both holes (see the PSO [Number of Holes](#)) and either bends (see the PSO [Number of Hemmed Bends](#)) or forms (see the PSO [Number of Forms](#)); it is 0 otherwise.

Number of Piercing Stations = {1 if there are holes and either bends or forms, and holes are pierced after forming, and there is hole forming; 0 otherwise}

The number of piercing stations is 1 if all the following hold:

- PSO [Number of Holes](#) is greater than 0.
- Either the PSO [Number of Hemmed Bends](#) greater than 0 or the PSO [Number of Forms](#) is greater than 0.
- PSO [Pierce Before or After Forms](#) is set to `holesAfterForms`.
- PSO [Number of Flanged or Countersunk Holes](#) is greater than 0 or the PSO [Number of Tapped Holes](#) is greater than 0.

Otherwise, the number of piercing stations is 0.

Number of Cam Piercing Stations = {number of plain hole groupings}

The number of cam piercing stations is the value of the PSO [Number of Plain Hole Groupings](#).

**Number of Extruding or Countersinking Stations = {
0 if there are no holes;
0 if there are no up features and no down features;
1 if there are up features and no down features;
1 if there down features and no up features;
2 otherwise}**

The number of extruding or countersinking stations is determined as follows:

- 0 if PSO [Number of Holes](#) is 0
- 0 if both the following hold:
 - PSO [Number of UP Flanged or Countersunk Holes](#) is 0
 - PSO [Number of DOWN Flanged or Countersunk Holes](#) is 0
- 1 if both the following hold:
 - PSO [Number of UP Flanged or Countersunk Holes](#) is greater than 0
 - PSO [Number of DOWN Flanged or Countersunk Holes](#) is 0
- 1 if both the following hold:
 - PSO [Number of UP Flanged or Countersunk Holes](#) is 0
 - PSO [Number of DOWN Flanged or Countersunk Holes](#) is greater than 0
- 2 otherwise

Number of Hole Threading Stations = {number of tapped holes}

The number of hole-threading stations is the value of the PSO [Number of Tapped Holes](#).

Number of Scoring Stations = {
0 if there are no bends with intersecting holes
0 if there are both up and down bends
1 otherwise}

The number of scoring stations is determined as follows:

- 0 if the PSO Number of Bends that Intersect with a Hole is 0
- 0 if both the following hold:
 - PSO Number of UP Bends is greater than 0
 - PSO Number of DOWN Bends is greater than 0

(In this case, any scoring is bundled with one of the bending operations.)

- 1 otherwise

Number of UP Bending Stations = {
2 if there are more than 3 UP bends;
1 if there are between 1 and 3 UP bends;
0 otherwise}

The number of UP bending stations is determined as follows:

- 2 if the PSO Number of UP Bends is greater than 3
- 1 if the PSO Number of UP Bends is between 1 and 3 (inclusive)
- 0 otherwise

Number of DOWN Bending Stations = {
2 if there are more than 3 DOWN bends;
1 if there are between 1 and 3 DOWN bends;
0 otherwise}

The number of DOWN bending stations is determined as follows:

- 2 if the PSO Number of DOWN Bends is greater than 3
- 1 if the PSO Number of DOWN Bends is between 1 and 3 (inclusive)
- 0 otherwise

Number of Cam Bending Stations = {number of bends over 95 degrees}

The number of cam bending stations is the value of the PSO Number of Bends that are Greater than 95 Degrees.

Number of UP Forming Stations = {
1 if there are UP forms and no UP bends;
0 otherwise}

The number of UP forming stations is 1 if both the following hold:

- PSO Number of UP Forms is greater than 0.
- PSO Number of UP Bends is 0.

Otherwise the number of UP forming stations is 0. (If there are UP forms and UP bends, the UP forming station is combined with the UP bending station.)

Number of DOWN Forming Stations = {
1 if there are DOWN forms and no DOWN bends;
0 otherwise}

The number of DOWN forming stations is 1 if both the following hold:

- PSO Number of DOWN Forms is greater than 0.
- PSO Number of DOWN Bends is 0.

Otherwise the number of DOWN forming stations is 0. (If there are DOWN forms and DOWN bends, the DOWN forming station is combined with the DOWN bending station.)

Number of Cam Forming stations = {number of forms over 90 degrees}

The number of cam forming stations is the value of the PSO Number of Undercut Forms.

Number of Restriking Stations = {1 if there are deep bends or forms; 0 otherwise}

The number of restriking operations is 1 if at least one of the following holds:

- PSO Number of Bends with Flap Length Over 75mm is greater than 0.
- The PSO Number of Forms with Depth Over 10mm is greater than 0.

Otherwise, the number of restriking stations is 0.

Number of Cutoff stations = 1

The number of cutoff stations is always 1.

Additional User Inputs

You can control the values listed below by modifying **Process Setup Options**, cost model variables, or toolshop variables.

To access **Process Setup Options** for a given process, right click the process in the Manufacturing Process pane, and select **Process Setup Options** from the context menu.

The following options control the addition of extra space (for various purposes) around blanks, between blanks, and between blanks and the coil edge:

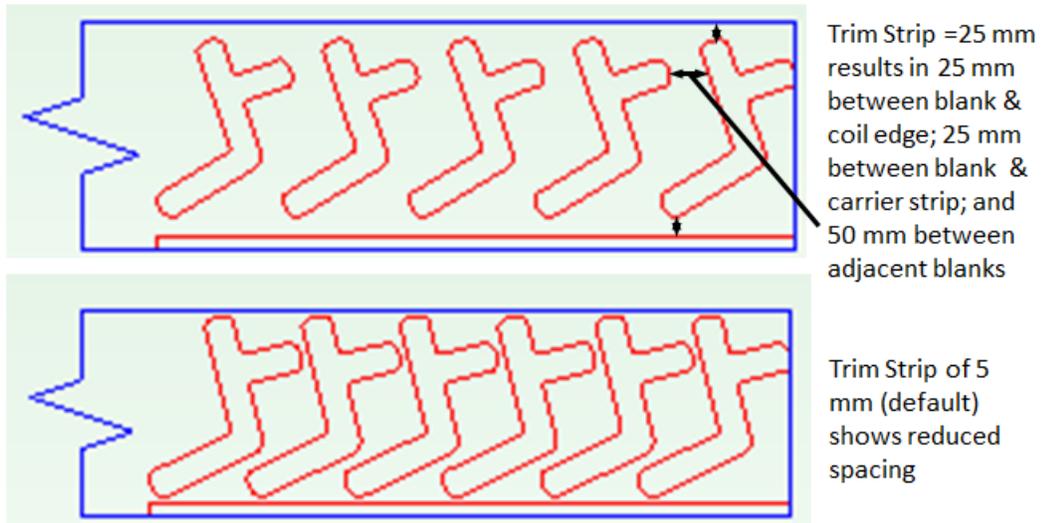
- **Press Carrier Strip Type**: controls type and number of carrier strips.
- **Single Edge Carrier Strip Width**: adds material for carrier strip.
- **Double Edge Carrier Strip Width**: adds material for carrier strips.
- **Press French Stop**: adds space for a French stop.
- **Width of Addendum Added to Blank Size [per side]**: adds material for holding during stamping.
- **Trim Strip Applied to Length and Width of Part**: adds space for cutting a part without damaging adjacent parts.
- **Pitch Margin Adder for Center Carrier Strip Type**: adds space for pilot holes in a center-type carrier strip
- **Coil Pitch**: supersedes the PSOs above to specify pitch dimension of blank plus extra space.
- **Coil Width**: supersedes the PSOs above to specify pitch dimension of blank plus extra space.
- **Maximum Strip Width**: constrains coil width.
- **Minimum Strip Width**: constrains coil width.

The following additional options are provided:

- **Number of Parts Stamped Concurrently**
- **Blank XY Orientation within Part Strip**
- **Pierce Before or After Forms**

Trim Strip Applied to Length and Width of Part

Width of a strip of material added all around the flattened blank, to provide some spacing between the blank and the carrier strip and between adjacent blanks (5.00 mm, by default in aPiori starting point VPEs). This addition of material provides sufficient space between parts to accommodate cutting the part without damaging the immediately adjacent items. Note that because the trim strip is added to both the leading and trailing sides of each blank (left and right sides of each blank, if the coil flow is left-to-right), the spacing between adjacent parts equals twice the value entered (10.00 mm, by default in aPiori starting point VPEs).



Select one of the following options:

- Default: value of the cost model variable **defaultEdgeMarginWidth** (5.00 in aPriori starting point VPEs)
- User Override: enter a value greater than or equal to 0.

Width of Addendum Added to Blank Size [per side]

An offset to be added all around the perimeter of the flattened part. You can enter a non-zero value in order to add additional material for the purpose of holding the blank during the stamping process, which is subsequently trimmed away.

Select one of the following options:

- No Addendum: this is the default.
- Computed Based on Form Depth: based on lookup by total form depth (see the PSO **Total Depth of Forms**) in the lookup table **blankAddendumWidth**.
- User Override: enter a value greater than or equal to 0.

Maximum Strip Width

By default, the maximum width of the stock strip is specified by the cost model variable **maximumStripWidth** (1828.8mm in aPriori starting point VPEs). To explicitly specify the maximum width select one of the following options:

- Default
- User Override

Minimum Strip Width

By default, aPriori determines the minimum width of the stock strip based on the blank SER dimensions. To explicitly specify the minimum width select one of the following options:

- Default
- User Override

Number of Parts Stamped Concurrently

Specifies whether two parts can be stamped concurrently. Select one of the following options:

- Evaluate Strip Nesting Layout: 1 Out (default)
- Evaluate Strip Nesting Layout: 2 Out

Blank XY Orientation within Part Strip

Specifies the blank orientation within the part strip. Select one of the following options:

- **Lengthwise:** blank SER length aligns with pitch direction.
- **Widthwise:** blank SER width aligns with pitch direction.

Pierce Before or After Forms

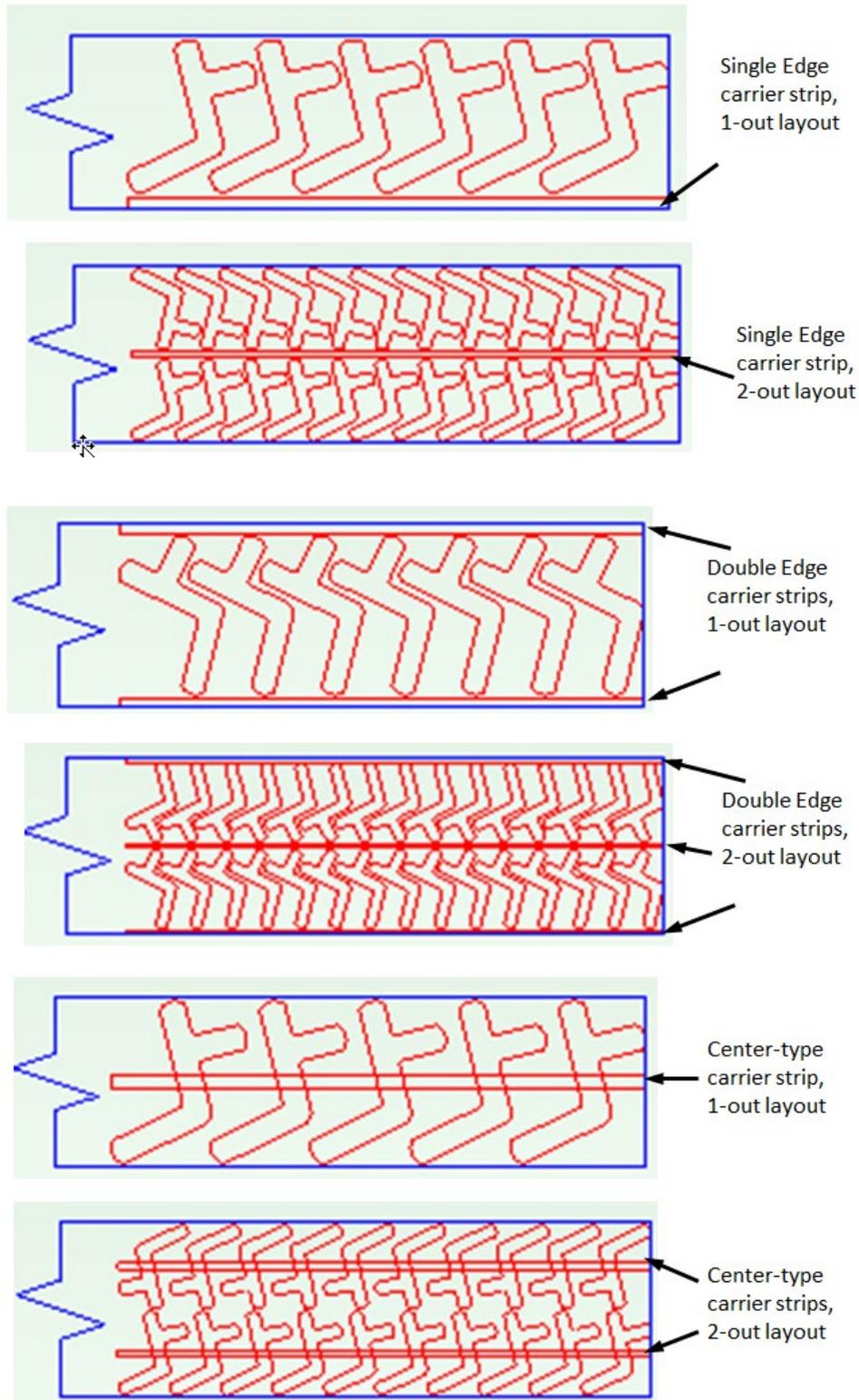
Affects number of dies stations. Select one of the following options:

- Default: **holesAfterForms**
- User Override: select one of the following:
 - **holesBeforeForms**
 - **holesAfterForms**

Press Carrier Strip Type

Number and position of the carrier strips that are used to convey the stamped blanks from die station to die station. Select one of the following options:

- Default: aPriori chooses a default carrier strip type based on the blank's SER length (see the PSO [Length](#)). A double edge strip is used if the length is greater than the cost model variable **largeProgDiePartSizeThreshold**; a single edge strip is used otherwise.
- User Override:
 - **singleEdge:** Only one carrier strip is used for each row of blanks, located on one side of the row.
 - **doubleEdge:** Two carrier strips are used for each row of blanks, located on each side of the row.
 - **center:** Only one carrier strip is used for each row of blanks, located in the middle of the row.



Single Edge Carrier Strip Width

Width to be added to the coil to accommodate a single edge carrier strip (see Press Carrier Strip Type). Select one of the following options:

- Default: value of the cost model variable **singleEdgeCarrierStripWidth** (20 mm in aPriori starting point VPEs).
- User Override: enter a value greater than or equal to 0.

(Note that no additional width is required for center-type carrier strips, since they are located in the middle of the row of nested blanks and are assumed never to extend beyond the blank edges.)

Double Edge Carrier Strip Width

Width to be added to the coil to accommodate a double edge carrier strip (see [Press Carrier Strip Type](#)). Select one of the following options:

- Default: value of the cost model variable **doubleEdgeCarrierStripWidth** (16 mm in aPriori starting point VPEs).
- User Override: enter a value greater than or equal to 0.

When you use double-edge type carrier strips with double-row nesting layouts, there are actually 3 strips: one at the top edge of the coil, one at the bottom edge of the coil, and one between the two rows of parts. (So the total contribution to coil width is 3*double edge carrier strip width, or 48 mm by default in aPriori starting point VPEs).

(Note that no additional width is required for center-type carrier strips, since they are located in the middle of the row of nested blanks and are assumed never to extend beyond the blank edges.)

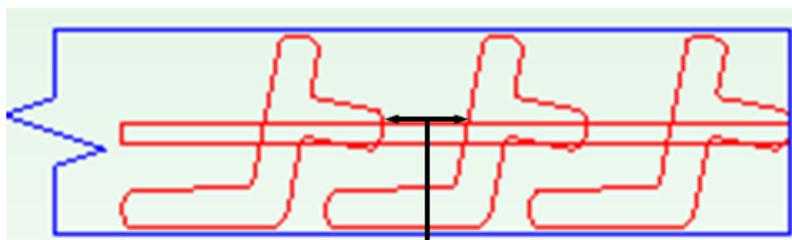
Pitch Margin Adder for Center Carrier Strip Type

Only used with center-type carrier strips. The trim strip length for a center carrier strip (16.00 mm, by default, in aPriori starting point VPEs) extends the horizontal spacing between adjacent blanks, in order to provide adequate space for pilot holes located in the carrier strip. The total length of the carrier strip between adjacent blanks is the sum of the following:

- Twice the trim strip for length and width of part
- Trim strip for center carrier strip
- Twice the addendum width

(This sum defaults to 26.00 mm in aPriori starting point VPEs.)

This center carrier strip trim strip value affects the pitch computation only when center carrier strips are in use; it is not applied for single-edge or double-edge carrier strips.



total spacing = 2*trim strip for length and width of part +
trim strip for center carrier strip + any addendum

Select one of the following options:

- Default: value of the cost model variable **defaultPartStripSpacing** (16.00 in aPriori starting point VPEs)
- User Override: enter a value greater than or equal to 0.

Press French Stop

Specifies whether to use a French stop (a notch on the edge of the coil) in order to keep the coil appropriately aligned with the die stations (the notch acts as a positive stop as the coil advances). If used, extra width must be added to the coil width to provide sufficient space for the notch. Select one of the following options:

- Standard French Stop: add the default extra width for a French stop, the value of the cost model variable **defaultFrenchStopSize** (3.0 mm in aPriori starting point VPEs).
- No French Stop: no extra width is added. This is the default.
- User Override: enter a value greater than or equal to 0, the width to be added.

Coil Pitch

Coil pitch is the extent of the blank along the direction of coil flow, supplemented by specified trim strip and addendum widths. By default, this is the sum of the following:

- Extent of the blank in the direction of coil flow
- 2 * Addendum Width
- 2 * Trim Strip for Length and Width of Part
- Trim Strip for Center Carrier Strip, if specified.

You can override the default with this option, which affects material costs and utilization, machine selection, and cycle time. It is your responsibility to ensure that the overrides have legal results, for example, that the resulting blanks do not overlap.

Select one of the following options:

- Default: calculated by aPriori (as described above)
- User Override: enter a value in millimeters or inches that is greater than or equal to 1.0 mm.

Coil Width

Coil width is the extent of the blank perpendicular to the direction of coil flow, supplemented by trim strip, addendum, and French-stop widths. By default, this is the sum of the following:

- Extent of the blank perpendicular to the direction of coil flow
- 2 * Addendum Width
- 2 * Trim Strip for Length and Width of Part
- Width(s) of Double Edge or Single Edge Carrier Strip(s)
- Press French Stop width

Note that with double-edge carrier strips for 2-out layouts, there are 3 carrier strips in total--one at the outermost edge of each row, and one in between the rows.

Note also that center-type carrier strips don't add additional width.

You can override the default with this option, which affects material costs and utilization, and the die size calculation for machine selection.

Select one of the following options:

- Default: calculated by aPriori (as described above)
- User Override: enter a value greater than or equal to 0.

Process Defaults and Thresholds

This section lists some of the important cost model variables and toolshop variables.

pressTableWidthMargin	See Machine Selection.
pressTableLengthMargin	See Machine Selection.
upperCoilWidthThreshold	See Machine Selection.
lowerCoilWidthThreshold	See Machine Selection.
defaultPartSpacing	See Machine Selection.
defaultDieSpacing	See Machine Selection.
customCutMultiplier	See Material Cost and Utilization.
defaultXyOrientation	See Material Cost and Utilization.
defaultEdgeMargin	See Material Cost and Utilization and Trim Strip Applied to Length and Width of Part.
defaultPartStripSpacing	See Material Cost and Utilization and Pitch Margin Adder for Center Carrier Strip Type.
singleEdgeCarrierStripWidth	See Material Cost and Utilization.
doubleEdgeCarrierStripWidth	See Material Cost and Utilization.
maximumStripWidth	See Material Cost and Utilization and Maximum Strip Width.
drawRate	See Cycle Time Calculation.
upperBlankPerimeterLengthThreshold	See Tooling Calculation.
lowerBlankPerimeterLengthThreshold	See Tooling Calculation.
defaultEdgeMarginWidth	See Trim Strip Applied to Length and Width of Part.
largeProgDiePartSizeThreshold	See Press Carrier Strip Type.
defaultFrenchStopSize	See Press French Stop.

The toolshop variables **avgLaborRate** and **avgMatlRate** affect tooling costs—see Tooling Calculation.



28 User Guided Sheet Metal—Stage Tooling

This section describes the costing details and inputs that are available for User Guided Stage Tooling. This process is part of the User Guided process group for UG Sheet Metal VPEs. See [User Guided Costing](#) for an introduction to user-guided costing.

For this process, aPriori estimates manufacturing times and costs for high-volume sheet metal parts. The routing can include secondary surface treatment and packaging processes (if you have licensed these modules). Since this is not a GCD-driven cost model, cost estimates are not based on a CAD model and geometry extraction; rather, basic geometric inputs (such as blank dimensions and number of bends and forms) are provided by the user. See [Sheet Metal](#) for the GCD-driven stage tooling cost model.

The chapter includes the following sections:

- Cost Model Overview
 - Geometric Inputs
 - Feasibility and Routing
 - Cost Algorithms and Calculations
 - Additional User Inputs
 - Process Defaults and Thresholds
-

Cost Model Overview

With some notable differences, the user guided stage tooling cost model is based on the same calculations as the GCD-driven cost model for progressive die found in the Sheet Metal process group.

An important difference between the user guided model and the GCD-driven model is that the latter assigns operations to individual GCDs, and then uses operation precedence and operation compatibility rules to assign operations to stages. The user guided model, in contrast, uses geometric inputs (such as number of up bends, number of down bends, number of up forms, and number of down forms) to estimate the total number of stages. Together with a calculated estimate of average die cost per die station, this allows the user guided model to determine tooling costs.

In general, costs are determined by aggregating material, labor, machine, and tooling costs.

This overview section summarizes assumptions and limitations of the following aspects of the model:

- General Process
- Part Geometry
- Materials
- Machines
- Tooling

General Process

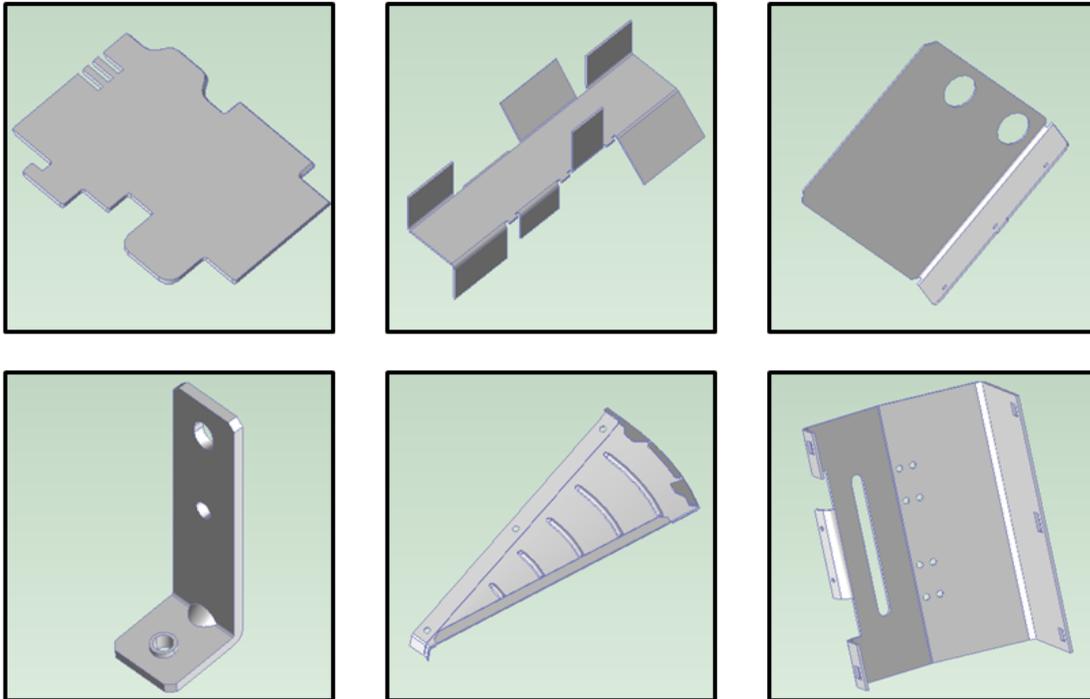
User Guided Stage tooling uses a series of presses with customized dies for the outline, bends, and holes for a given part. Presses are the same as those used for standard press operations. The tools tend to be simple and incorporate a number of simple tools within the die.

User Guided Stage Tooling does *not* support deep draw forming operations, side-action forming (cam-actuated), multiple trim stages, hole piercing prior to or subsequent to bending and forming operations, or concurrent stamping of multiple parts.

If you have licensed the appropriate modules, your routing can include optional heat treatment, surface treatment, and packaging processes.

Part Geometry

A small selection of example parts is shown below.



Geometry extraction is replaced by geometric inputs in the user guided cost model. For progressive die, these inputs include, among others, the following:

- Part volume
- Flat pattern blank dimensions and perimeter
- Number of bends and forms
- Total hole perimeter and total form perimeter
- Total form depth and total bend length
- Number of bends over 95°

See [Geometric Inputs](#) for more information.

Materials

Materials include the following:

- Aluminum: 3003, 5052, 6061
- Copper: 110
- Galvanized Steel: HR-1010, HR-1012, HR-1020
- Stainless Steel: 304, 316, 316L
- Steel: CR-1010, CR-1012, CR-1020, HR-1010, HR-1012, HR-1020

Material composition details include the following:

- Unit Cost (USD / kg)
- Density (kg / m³)
- Shear Strength (MPa)
- Ultimate Tensile Strength (MPa)

Material details include equivalent DIN and EN name standards for use with regional VPEs.

See [Material Selection](#) for more information.

Machines

The following tables list important machine property value ranges. Ranges are listed below for those processes that support a choice of machines:

Stage Press

Property	Low End	High End
Max Part Length (mm)	703.0	3,403.6
Max Part Width (mm)	609.6	1,501.14
Press Force (kN)	658.0	6,636.0

See [Machine Selection](#) for more information.

Tooling

Total progressive die tooling cost can be specified with the [PSO Total Stage Tooling Tool Cost](#) or calculated as follows:

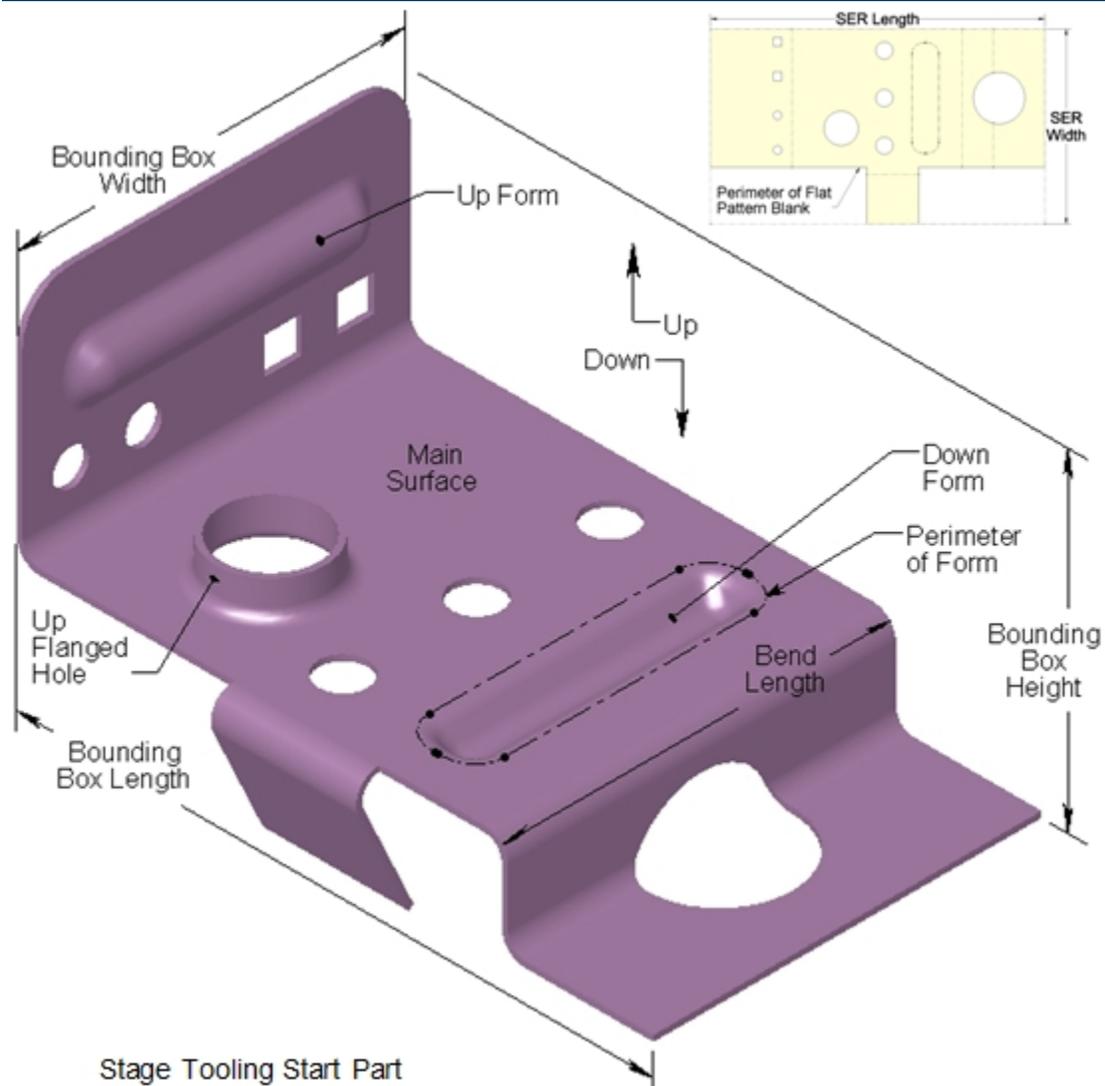
$$\text{Hard Tooling Cost} = \text{Number of Stages} * (\text{Average Material Cost per Stage} + \text{Average Labor Cost per Stage})$$

The values in this formula are estimated based on geometric inputs such as number of holes and forms, flat pattern blank area, and the number of bends over 95 degrees. See [Tooling Calculation](#) for more information.

Geometric Inputs

This section covers the Process Setup Options (PSOs) that serve as substitutes for the geometry extraction performed by GCD-driven cost models.

The following start part image provides an overview of the relevant, user-supplied, geometric values:



Follow these guidelines to ensure that your part will cost:

- 1 Create a virtual part and use the settings from an appropriate start part (select or search for the start part scenario from the **Recently Used Settings** menu of the Cost Guide's Production Scenario tab—see [Using Settings from a Start Part](#)).
- 2 Open the **User Guided** node in the Process and Machine Options tab of the Cost Guide. Supply a nonzero value for the required PSO [Part Volume](#).
- 3 Open the **Sheet Metal PG** node in the Process and Machine Options tab of the Cost Guide. Supply a nonzero value for all the following required PSOs:
 - o Thickness of Part
 - o Length of the flat pattern's Smallest Enclosing Rectangle
 - o Width of the flat pattern's Smallest Enclosing Rectangle

Ensure that Length of the flat pattern's Smallest Enclosing Rectangle is greater than or equal to Width of the flat pattern's Smallest Enclosing Rectangle.

- 4 If your routing includes surface treatment or other secondary processes, supply nonzero values for all the following PSOs (the **Sheet Metal PG** node):

- Length of the finished part's Bounding Box
- Width of the finished part's Bounding Box
- Height of the finished part's Bounding Box

Ensure that Length of the finished part's Bounding Box is greater than or equal to Width of the finished part's Bounding Box, and that Width of the finished part's Bounding Box is greater than or equal to Height of the finished part's Bounding Box.

- 5 If your routing includes surface treatment, supply a non-zero value for the PSO Surface Area of Part (in the **Sheet Metal PG** node).
- 6 Open the **Stage Tooling Routing** node. Supply a non-zero value for **Perimeter of the flat pattern blank**. Supply a value for all the other required PSOs; if you or your start part supplies a value greater than 0, also supply *consistent* values for the associated, *conditionally* required PSOs. Each required PSO's associated conditionally required PSOs are listed below, together with their consistency requirements.
- 7 Open the **Stage Tooling** node. If you or your start part supplies values for the optional PSO **Number of Flanged or Countersunk Holes**, also supply *consistent* values for the associated, *conditionally* required PSOs **Number of UP Flanged or Countersunk Holes** and **Number of DOWN Flanged or Countersunk Holes**, and ensure that the UP and DOWN values sum to the total number of flanged or countersunk holes.

The following table lists the Progressive Die Routing node required PSO's. Any associated conditionally required PSOs are shown together with their consistency requirements:

Stage Tooling Routing node Required PSO	Associated Conditionally Required PSO
▪ Perimeter	None
▪ Number of Holes	▪ Total Perimeter
▪ Number of Bends	▪ Total Length ▪ Number of UP Bends ▪ Number of DOWN Bends Ensure that total perimeter is nonzero and that the number of UP and DOWN bends sums to Number of Bends.
▪ Number of Forms	▪ Total Perimeter ▪ Total Depth of Forms ▪ Number of UP Forms ▪ Number of DOWN Forms Ensure that total perimeter is nonzero and that the number of UP and DOWN forms sums to Number of Forms.

The following table lists the Stage Tooling node optional PSO that has associated conditionally required PSOs. The associated conditionally required PSOs are shown together with their consistency requirements:

Stage Tooling node Optional PSO	Associated Conditionally Required PSOs
<ul style="list-style-type: none"> Number of Flanged or Countersunk Holes 	<ul style="list-style-type: none"> Number of UP Flanged or Countersunk Holes Number of DOWN Flanged or Countersunk Holes <p>Ensure that these values sum to Number of Flanged or Countersunk Holes.</p>

The Progressive Die node has several other important geometric PSOs. All the geometric PSOs are described in detail in the following sections:

- User Guided Node
- Sheet Metal PG Node
- Stage Tooling Routing Node
- Stage Tooling Node

Non-geometric PSOs are described in [Additional User Inputs](#).

User Guided Node

The top-level PSO node includes one PSO, which is required. If you do not supply a value for this PSO, the part fails to cost.

Status	Process Step
●	User Guided Costing
●	Sheet Metal PG
●	Stage Tooling Routing
●	Stage Tooling

Part Volume

Required

Part volume is a required input for all user guided processes. This is the volume of the material that constitutes the part. Part volume contributes to material cost and utilization (see [Material Cost and Utilization](#)) and to cycle time (see [Cycle Time Calculation](#)).

***Part Volume (Piece Part & Tooling Cost Driver)**
Used to calculate part mass and various values impacting part and tooling cost

User Required(>=0.000): mm³

Enter a value greater than 0.

Sheet Metal PG Node

The Sheet Metal PG node includes PSOs that apply to all user guided sheet metal parts.

Status	Process Step
	User Guided Costing
	Sheet Metal PG
	Stage Tooling Routing
	Stage Tooling

This node includes three required inputs related to the dimensions of the flattened blank:

- Thickness of Part
- Length of the flat pattern's Smallest Enclosing Rectangle
- Width of the flat pattern's Smallest Enclosing Rectangle

***Thickness of Part**
Enter the thickness of the metal used to make the part
 User Required(≥ 0.000): mm

***Length of the flat pattern's Smallest Enclosing Rectangle**
The SER is the smallest rectangle that completely encloses the flat pattern
 User Required(≥ 0.000): mm

***Width of the flat pattern's Smallest Enclosing Rectangle**
The SER is the smallest rectangle that completely encloses the flat pattern
 User Required(≥ 0.000): mm

This node also includes three conditionally required inputs, related to the part dimensions:

- Length of the finished part's Bounding Box
- Width of the finished part's Bounding Box
- Height of the finished part's Bounding Box

****Length of the finished part's Bounding Box**
Length is the longest dimension of the Bounding Box
 User Required(≥ 0.000): mm

****Width of the finished part's Bounding Box**
Width is the second longest dimension of the Bounding Box
 User Required(≥ 0.000): mm

****Height of the finished part's Bounding Box**
Height is the shortest dimension of the Bounding Box
 User Required(≥ 0.000): mm

Finally, there is a conditionally required PSO for surface area:

- Surface Area of Part

****Surface Area of the Part**

Required if this scenario includes secondary processes

This drives the cost of secondary processes like plating, anodizing, powder coating, etc

User Override(≥ 0.000): mm²

Thickness of Part

Required

This is the thickness of the stock used to create the part. This value contributes to material utilization via blank mass (see [Material Cost and Utilization](#)), and affects machine selection via required press force (see [Machine Selection](#)).

Enter a value greater than 0.

Length of the flat pattern's Smallest Enclosing Rectangle

Required

This is the longer dimension of the flattened part's smallest enclosing rectangle (that is, SER length > SER width). (Note this is *not* the length of the stock used for the part—the stock includes additional space for addenda and margins.) It contributes to material utilization (see [Material Cost and Utilization](#)) and tooling cost (see [Tooling Calculation](#)). It also affects machine selection (see [Machine Selection](#)).

Enter a value greater than 0.

Width of the flat pattern's Smallest Enclosing Rectangle

Required

This is the shorter dimension of the flattened part's smallest enclosing rectangle (that is, SER length > SER width). (Note this is *not* the width of the stock used for the part—the stock includes addition space for addenda and margins.) It contributes to material utilization (see [Material Cost and Utilization](#)) and tooling cost (see [Tooling Calculation](#)). It also affects machine selection (see [Machine Selection](#)).

Enter a value greater than 0.

Length of the finished part's Bounding Box

Optional; may be required for secondary processes.

This is the longer dimension of the finished part's smallest enclosing box (that is, bounding box length > bounding box width). It may contribute to calculations for secondary processes. A value of 0 is used by default.

Enter a value greater than 0.

Width of the finished part's Bounding Box

Optional; may be required for secondary processes.

This is the shorter dimension of the finished part's smallest enclosing box (that is, bounding box length > bounding box width). It may contribute to calculations for secondary processes. A value of 0 is used by default.

Enter a value greater than 0.

Height of the finished part's Bounding Box

Conditionally required; may be required for secondary processes.

This is the height of the finished part's bounding box—the dimension of the bounding box that is perpendicular to the flat pattern blank. It may contribute to calculations for secondary processes. A value of 0 is used by default.

Enter a value greater than 0.

Surface Area of Part

Optional; may be required for secondary processes.

This is the surface area of the material comprising the finished part. It may contribute to calculations for secondary processes. A value of 0 is used by default.

Enter a value greater than 0.

Stage Tooling Routing Node

The Stage Tooling Routing node includes required and conditionally required PSOs. A conditionally required PSO is one that is required if you have entered a nonzero value for a particular, related PSO. For example, Total Hole Perimeter is required if you have entered a nonzero value for Number of Holes.

If you don't enter a value for a required PSO, the part fails to cost. If you don't enter a value for a conditionally required PSO when its associated condition is met, the part fails to cost.

Status	Process Step
	User Guided Costing
	Sheet Metal PG
	Stage Tooling Routing
	Stage Tooling

The following PSOs are required:

- Perimeter of the flat pattern blank
- Number of Holes
- Number of Bends
- Number of Forms

The following PSOs are conditionally required:

- Total Perimeter of Holes
- Total Length of Bends
- Number of UP Bends
- Number of DOWN Bends
- Total Perimeter of Forms
- Total Depth of Forms
- Number of UP Forms
- Number of DOWN Forms

Perimeter of the flat pattern blank

Required

This is the perimeter of the flattened part. It affects the number of trimming stages, which affects tooling costs (see [Tooling Calculation](#)). It also affects required press force, which affects machine selection (see [Machine Selection](#)).

Number of Holes

Required

This is the number of holes in the finished part. It affects the number of stages, as well as tooling material and tooling labor costs per die station (see [Tooling Calculation](#)).

If you enter a value for this PSO, you must also enter a value for [Total Perimeter of Holes](#).

Enter a value greater than or equal to 0.

Total Perimeter of Holes

Conditionally required

You must enter a value for this PSO if you entered a nonzero value for Number of Holes. It is the sum of the perimeters of all holes. It affects required press force, which affects machine selection (see [Machine Selection](#)).

Enter a value greater than 0.

Number of Bends

Required

This is the number of bends that need to be created in order to make the part. It affects average labor hours per stage, average die material mass per stage, and number of stages (see [Tooling Calculation](#)).

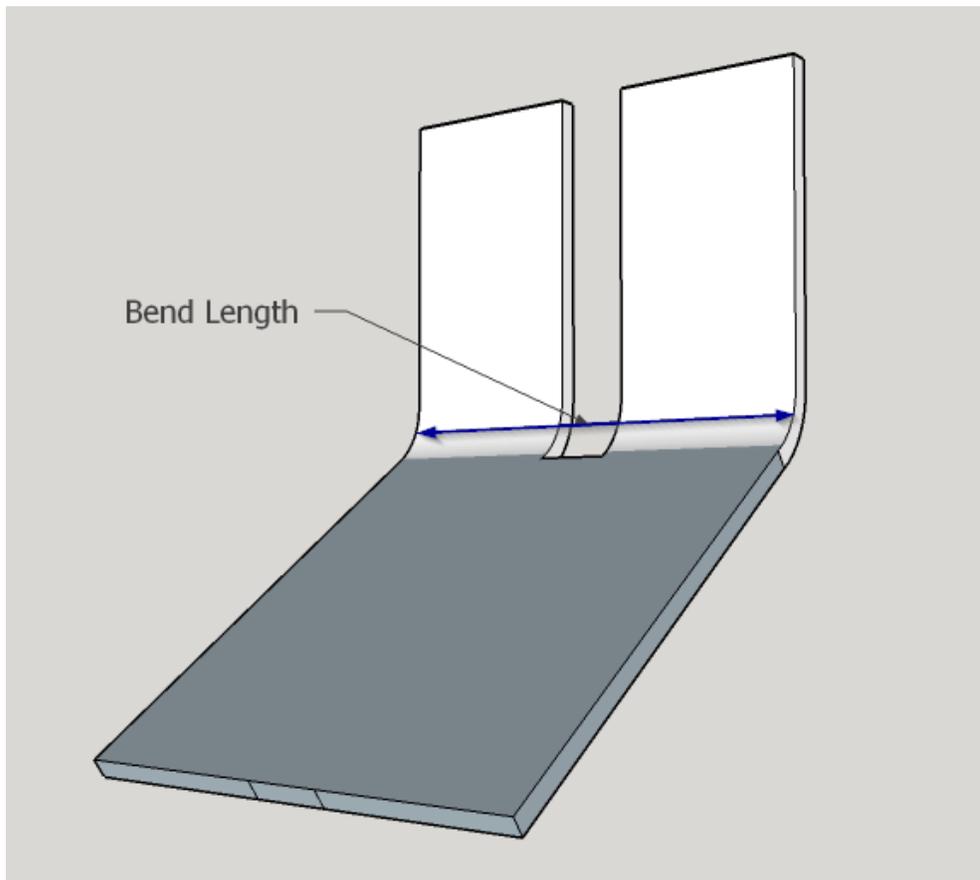
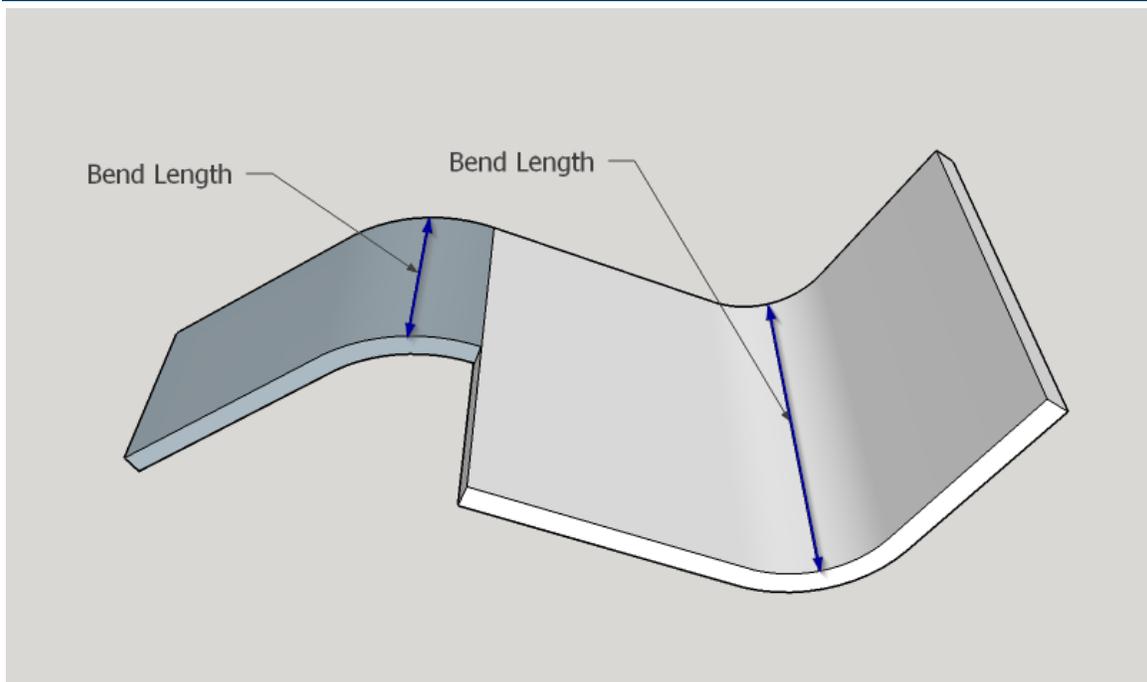
If you enter a value for this PSO, you must also enter a value for [Total Length of Bends](#), [Number of UP Bends](#), and [Number of DOWN Bends](#).

Enter a value greater than or equal to 0.

Total Length of Bends

Conditionally required

You must enter a value for this PSO if you entered a nonzero value for Number of Bends. It is the sum of the lengths of all bends. It contributes to required press force, which affects machine selection (see [Machine Selection](#)).



Enter a value greater than 0.

Number of UP Bends

Conditionally required

You must enter a value for this PSO if you entered a nonzero value for Number of Bends. This is the number of bends performed in the UP direction with respect to the part's main surface. It affects the number of stages, which contributes to tooling costs (see [Tooling Calculation](#)).

Enter a value greater than or equal to 0.

Number of DOWN Bends

Conditionally required

You must enter a value for this PSO if you entered a nonzero value for Number of Bends. This is the number of bends performed in the DOWN direction with respect to the part's main surface. It affects the number of stages, which contributes to tooling costs (see [Tooling Calculation](#)).

Enter a value greater than or equal to 0.

Number of Forms

Required

This is the number of forms that need to be created in order to make the part. It affects average labor hours per die station, average die material mass per die station, and number of stages (see [Tooling Calculation](#)).

If you enter a value for this PSO, you must also enter a value for [Total Perimeter of Forms](#), [Total Depth of Forms](#), [Number of UP Forms](#), and [Number of DOWN Forms](#).

Enter a value greater than or equal to 0.

Total Perimeter of Forms

Conditionally required

You must enter a value for this PSO if you entered a nonzero value for Number of Forms. It is the sum of the perimeters of all forms. It contributes to required press force, which affects machine selection (see [Machine Selection](#)).

Enter a value greater than 0.

Total Depth of Forms

Conditionally required

You must enter a value for this PSO if you entered a nonzero value for Number of Forms. It is the sum of the depths of all forms. It contributes to the computed blank addendum width (see [Width of Addendum Added to Blank Size \[per side\]](#)).

Form depth is the distance from the surface containing the form to the form's farthest point. It is measured along a normal to the surface.

Enter a value greater than 0.

Number of UP Forms

Conditionally required

You must enter a value for this PSO if you entered a nonzero value for Number of Forms. This is the number of forms created in the UP direction with respect to the part's

main surface. It affects the number of stages, which contributes to tooling costs (see [Tooling Calculation](#)).

Enter a value greater than or equal to 0.

Number of DOWN Forms

Conditionally required

You must enter a value for this PSO if you entered a nonzero value for Number of Forms. This is the number of forms created in the DOWN direction with respect to the part's main surface. It affects the number of stages, which contributes to tooling costs (see [Tooling Calculation](#)).

Enter a value greater than or equal to 0.

Stage Tooling Node

This Stage Tooling node includes optional PSOs, as well as some conditionally required PSOs.

Status	Process Step
	 User Guided Costing
	 Sheet Metal PG
	 Stage Tooling Routing
	 Stage Tooling

This section lists the PSOs in this node that act as substitutes for the geometry extraction performed for GCD-driven process groups. Other PSOs associated with this node are listed in [Additional User Inputs](#).

The following PSOs are optional:

- Number of Stages
- Average Toolshop Labor Hours per Stage
- Average Toolshop Labor Rate
- Average Mass of Material per Stage
- Average Material Rate of Mold Materials
- Total Stage Tooling Tool Cost
- Number of Flanged or Countersunk Holes
- Number of Tapped Holes
- Number of Bends that are Greater than 95 Degrees

The following PSOs are conditionally required:

- Number of UP Flanged or Countersunk Holes
- Number of DOWN Flanged or Countersunk Holes

Number of Stages

Optional

By default, the number of stages required by the current part is calculated as described in [Tooling Calculation](#). You can override this value and specify the number of stages explicitly with this PSO.

Enter a value greater than or equal to 0.

Average Toolshop Labor Hours per Stage

Optional

By default, the average time per stage of labor spent on the manufacture of tooling is calculated as described in [Tooling Calculation](#). You can override this value and specify labor hours explicitly with this PSO.

Enter a value greater than or equal to 0.

Average Toolshop Labor Rate

Optional

By default, the average labor rate per stage for the manufacture of tooling is specified by the toolshop variable **Avg Labor Rate**. You can override this value and specify the labor rate explicitly with this PSO.

Enter a value greater than or equal to 0.

Average Mass of Material per Stage

Optional

By default, the average mass per stage of the tooling required for the current part is calculated as described in [Tooling Calculation](#). You can override this value and specify tooling mass explicitly with this PSO.

Enter a value greater than or equal to 0.

Average Material Rate of Mold Materials

Optional

By default, the average per-stage raw material cost per kilogram for tooling is specified by the toolshop variable **Avg Matl Rate**. You can override this value and specify the material rate explicitly with this PSO.

Enter a value greater than or equal to 0.

Total Stage Tooling Tool Cost

Optional

By default, the total cost of the manufacture of the tooling required for the current part is calculated as described in [Tooling Calculation](#). You can override this value and specify the total tooling cost explicitly with this PSO.

Enter a value greater than or equal to 0.

Number of Flanged or Countersunk Holes

Optional

By default, the number of flanged or countersunk holes is assumed to be 0. You can override the default with this PSO.

If you enter a value greater than 0 for this PSO, you must supply values for the PSOs [Number of UP Flanged or Countersunk Holes](#) and [Number of DOWN Flanged or Countersunk Holes](#).

Enter a value greater than or equal to 0.

Number of UP Flanged or Countersunk Holes

Conditionally Required

If you enter a value greater than 0 for Number of Flanged or Countersunk Holes, you must supply a value for this PSO. This is the number of holes that are flanged or countersunk in the UP direction with respect to the part's main surface. This value affects the number of stages, which contributes to tooling costs (see [Tooling Calculation](#)).

Enter a value greater than or equal to 0.

Number of DOWN Flanged or Countersunk Holes

Conditionally Required

If you enter a value greater than 0 for Number of Flanged or Countersunk Holes, you must supply a value for this PSO. This is the number of holes that are flanged or countersunk in the DOWN direction with respect to the part's main surface. This value affects the number of stages, which contributes to tooling costs (see [Tooling Calculation](#)).

Enter a value greater than or equal to 0.

Number of Tapped Holes

Optional

By default, the number of tapped holes is assumed to be 0. You can override the default with this PSO.

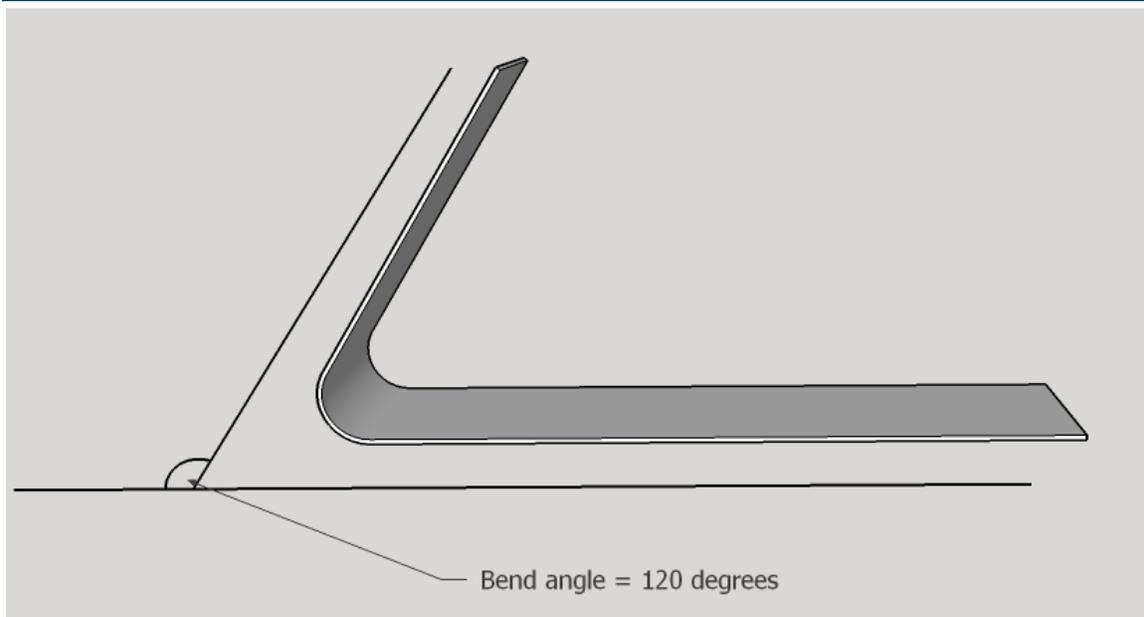
Enter a value greater than or equal to 0.

Number of Bends that are Greater than 95 Degrees

Optional

By default, the number of bends greater than 95 degrees is assumed to be 0. You can override the default with this PSO. The value determines the number of cam bending stages—see [Tooling Calculation](#).

Enter a value greater than or equal to 0.



Feasibility and Routing

When you choose the Sheet Metal process group, aPiori selects process-level routings, as well as machines and materials. These procedures are described in the following sections:

- Process-level Feasibility
- Material Selection
- Machine Selection

Process-level Feasibility

Process feasibility depends on the values you supply for the geometric PSOs. The process is feasible only if all the following hold:

- You have supplied values for all required PSOs.
- You have supplied nonzero values for part volume, blank SER width, blank SER length, blank thickness, and part height.
- For each conditionally required PSO, you have supplied a nonzero value if and only if you have supplied a nonzero value for its associated PSO. For example, you have supplied a nonzero value for total bend length if and only if you have supplied a nonzero value for number of bends.
- If you supplied a value greater than 0 for number of bends, the values you supplied for number of UP bends and number of DOWN bends sum to the number of bends.
- If you supplied a value greater than 0 for number of forms, the values you supplied for number of UP forms and number of DOWN forms sum to the number of forms.
- If you supplied a value greater than 0 for number of flanged or countersunk holes, the values you supplied for number of UP flanged or countersunk holes and number of DOWN flanged or countersunk holes sum to the number of flanged or countersunk holes.

- If your routing includes surface treatment or other secondary processes, you have supplied values for part bounding box length, part bounding box width, and part surface area.

For detailed information on all these PSOs, see [Geometric Inputs](#).

Material Selection

In direct integration mode with Pro/ENGINEER, if the composition selection mode is **MCAD**, aPriori selects the MCAD composition from the part, if available. Otherwise aPriori selects the VPE default material (Steel, CR-1020).

In CAD-independent mode, aPriori selects the VPE default material (Steel, CR-1020 in aPriori starting point VPEs).

In both direct integration and CAD-independent mode, you can use aPriori's selection or else manually select a material composition and override the material unit cost. To manually specify a material, select **Edit > Material Selection** in the Manufacturing Process pane (see also [Selecting material in Manufacturing Process Information](#)). You can override the unit cost if desired.

All material stock is virtual stock. Material Stock dimensions are given by the PSOs [Thickness of Part](#), [Length of the flat pattern's Smallest Enclosing Rectangle](#), and [Width of the flat pattern's Smallest Enclosing Rectangle](#), together with the calculated or user-specified values for [Width of Addendum Added to Blank Size \[per side\]](#), [Stock Length Margin](#), and [Stock Width Margin](#) (see also [Material Cost and Utilization](#)).

Machine Selection

aPriori selects the default machine if it is feasible; otherwise, aPriori selects the feasible machine with the lowest overhead (specified by the sum of the machine properties **Direct Overhead Rate** and **Indirect Overhead Rate**).

The machine feasibility rules require that the machine can accommodate the following:

- [Stock Length and Width](#)
- [Required Press Force](#)

Stock Length and Width

Stock must fit on the press table. Table dimensions are specified by the machine properties **Press Table Width** and **Press Table Length**. Stock width is the sum of the following:

- Blank SER width (specified by the required PSO [Width of the flat pattern's Smallest Enclosing Rectangle](#))
- Addendum (0 by default, or specified by the PSO [Width of Addendum Added to Blank Size \[per side\]](#))
- Twice the stock width margin. The stock width margin is specified by the cost model variable **widthMarginStageTooling** (7.3mm in aPriori starting point VPEs) or the PSO [Stock Width Margin](#).

Similarly, stock length is the sum of the following:

- Blank SER length (specified by the required PSO [Length of the flat pattern's Smallest Enclosing Rectangle](#))

- Addendum (0 by default, or specified by the PSO [Width of Addendum Added to Blank Size](#) [per side])
- Twice the stock length margin. The stock length margin is specified by the cost model variable **lengthMarginStageTooling** (12.5 mm in aPriori starting point VPEs) or the PSO [Stock Length Margin](#).

Required Press Force

Required press force must not exceed the machine property **Press Force** (which is specified in kilonewtons). Required press force in newtons is the sum of the following:

- Required shear force, which is the product of the following:
 - Blank perimeter (specified by the PSO [Perimeter of the flat pattern blank](#)) plus total hole perimeter (specified by the PSO [Total Perimeter of Holes](#))
 - Blank thickness (specified by the PSO [Thickness of Part](#))
 - Material shear strength (specified by the material property **Shear Strength**).
- Required bending force, which is the product of the following:
 - Total bend length (specified by the PSO [Total Length of Bends](#))
 - Blank thickness (specified by the PSO [Thickness of Part](#))
 - Material property **Ultimate Tensile Strength**
- Required drawing force, which is the product of the following:
 - Total form perimeter (specified by the PSO [Total Perimeter of Forms](#))
 - Blank thickness (specified by the PSO [Thickness of Part](#))
 - Material property **Tensile Yield Strength**
- Required total holding force, which is the sum of the following:
 - 5% of required shear force
 - 10% of Required bending force
 - 30% of Required drawing force

Cost Algorithms and Calculations

This section details how costs are calculated by aPiori.

This section covers formulas in the following areas:

- Material Cost and Utilization
- Accounting Calculations
- Cycle Time Calculation
- Tooling Calculation

Material Cost and Utilization

Final Yield = Final Output Volume / Input Volume

Final yield affects material, labor, and overhead costs per part. It is the fraction of parts created by this process in the current production scenario that will survive as good parts once any secondary processes are completed. That is, final yield is the fraction of parts created by this process that are *not* discarded as scrap parts, either by this process or by a downstream process. Final yield depends on the following:

- Final Output Volume (product of the annual volume and number of production years, specified in the Production Scenario screen of the Cost Guide)
- Input volume (see the formula below). This is the total number of parts produced by this process, including all parts discarded as scrap from this process or downstream processes.

Input Volume = Local Output Volume + Number of Scrap Parts for This Process

Input volume is the total number of parts produced by this process in the current scenario, including all parts discarded as scrap from this process or downstream processes. It is the sum of the following:

- Local output volume (see the formula below). This is the number of parts produced by this process, excluding parts discarded as scrap by this process, but including parts that are discarded as scrap by downstream processes.
- Number of scrap parts for this process (see the formula below)

Local Output Volume = Final Output Volume + Number of Scrap Parts Downstream

Local output volume is the number of parts produced by this process in the current scenario, excluding parts discarded as scrap by this process, but including parts that are discarded as scrap by downstream processes. It is the sum of the following:

- Final output volume (product of volume and number of production years, specified in the Production Scenario screen of the Cost Guide)
- Number of Scrap Parts Downstream. This is the number of parts discarded as scrap by downstream processes.

Number of Scrap Parts for This Process = (Local Output Volume / Good Part Yield) – Local Output Volume

Number of scrap parts for this process is the number of parts produced by this process in the current scenario that are discarded as scrap by this process, before any downstream process is performed on them. It is a function of the following:

- Local output volume (see the formula above)

- Good part yield (specified by the machine property **Good Part Yield**). This is the fraction of parts produced by this process that are not discarded as scrap by this process but may be discarded as scrap by downstream processes.

Material Cost = ((Material Cost Per Mass * Custom Cut Multiplier * Part Mass) / Utilization) / Final Yield

aPiori calculates the cost for material based on the following factors:

- Material cost per mass (determined from **Material Stock** if stock is selected; otherwise, from **Material Composition** in the **Material Selection** dialog)
- Part mass (product of part volume and material density)
- Custom cost multiplier (specified by the cost model variable **customCutMultiplier**)
- Utilization (see formula below)
- Final Yield (see formula above)

Utilization = Part Mass / Blank Mass

Utilization depends on the following:

- Part mass (product of part volume and material density—see the **Part Volume** PSO and the **Density** property in the Materials table)
- Blank mass (see formula below)

Blank Mass = Stock Length * Stock Width * Blank Thickness * Material Density

Blank mass is the product of the following:

- Stock length (calculated using the formula below)
- Coil Width (calculated using the formula below)
- Blank thickness (specified by the PSO **Thickness of Part**)
- Material density (specified by the **Density** property in the Materials table)

Stock Length = Blank SER length + Addendum + (2 * Stock Length Margin)

Stock length depends on the following:

- Blank SER length (specified by the required PSO **Length of the flat pattern's Smallest Enclosing Rectangle**)
- Addendum (0 by default, or specified by the PSO **Width of Addendum Added to Blank Size [per side]**)
- Stock length margin is specified by the cost model variable **lengthMarginStageTooling** (12.5 mm in aPiori starting point VPEs) or the PSO **Stock Length Margin**.

Stock Width = Blank SER Width + Addendum + (2 * Stock Width Margin)

Stock length depends on the following:

- Blank SER width (specified by the required PSO **Width of the flat pattern's Smallest Enclosing Rectangle**)
- Addendum (0 by default, or specified by the PSO **Width of Addendum Added to Blank Size [per side]**)
- Stock length margin is specified by the cost model variable **lengthMarginStageTooling** (12.5 mm in aPiori starting point VPEs) or the PSO **Stock Width Margin**.

Accounting Calculations

Labor Cost = Labor Time * Labor Rate / Final Yield

Labor cost is a function of the following:

- Labor time (see formula below)
- Labor rate (specified by the machine property **Labor Rate**)
- Final yield (see the formula above)

Labor Time = Cycle Time * Labor Time Standard * Number of Operators

Labor time is the product of the following

- Cycle time (see the formula below)
- Labor time standard (specified as a machine property). This value reflects the amount of time spent by machine operators in between machine cycles, including time performing maintenance and cleaning tasks as well as time pausing between tasks. The amount is expressed as a cycle time multiplier.
- Number of operators (specified by the machine property **Number of Operators**)

Amortized Batch Setup =

(Setup Time * (Labor Rate + Direct Overhead Rate)) / Batch Size

Amortized batch setup depends on the following:

- Setup time per die station (specified as the machine property **Setup Time**)
- Labor rate (specified by the machine property **Labor Rate**)
- Direct overhead rate (see [Direct and Indirect Overhead](#))
- Batch size (specified in the **Production Scenario** screen of the Cost Guide)

Cycle Time Calculation

Cycle Time = (Press Cycle Time + Labor Handling Time) * Adjustment Factor

Cycle time is a function of the following:

- Press cycle time (specified by the machine property **Press Cycle Time**)
- Labor handling time (looked up by **Part Volume** in the lookup table **smGenericPressHandling**)
- Adjustment factor (specified by the cost model variable **cycleTimeAdjustmentFactor**). This factor is 1 in aPiori starting point VPEs. VPE administrators can modify **cycleTimeAdjustmentFactor** in order to adjust cycle times across processes within the current VPE.

Tooling Calculation

Total progressive die tooling cost can be specified with the **PSO Total Stage Tooling Tool Cost** or calculated as described below.

Hard Tooling Cost = Number of Die Stations *

(Average Material Cost per Die Station + Average Labor Cost per Die Station)

Hard tooling cost depends on the following

- Number of die stations (specified by the PSO **Number of Stages**, or calculated by using the formula below)
- Material cost per die station (see the formula below)

- Labor cost per die station (see the formula below)

Average Material Cost per Die Station = Average Material Mass per Die Station * Average Material Rate

Average material cost per die station is the product of the following:

- Average material mass per die station (calculated as described below, or specified by the PSO [Average Mass of Material per Stage](#))
- Average material rate (specified by the PSO [Average Material Rate of Mold Materials](#) or the toolshop variable [Avg Matl Rate](#)).

Average Material Mass per Die Station

Average material mass per die station is estimated as a linear combination of

- Blank SER area
- Total number of holes
- Total number of bends and forms

aPriori chooses between sets of coefficients to be used in the linear combination based on whether the part requires side actions (that is, whether there are cam bending stations--see the formula below)

The sets of coefficients are derived from large, representative data sets of sample of parts.

Average Labor Cost per Die Station = Average Labor Hours per Die Station * Average Labor Rate

Average labor cost per die station is the product of the following:

- Average labor hours per die station (calculated as described below, or specified by the PSO [Average Toolshop Labor Hours per Stage](#))
- Average labor rate (specified by the PSO [Average Toolshop Labor Rate](#) or the toolshop variable [Avg Labor Rate](#)).

Average Labor Hours per Die Station

Average labor hours per die station is estimated as a linear combination of

- Blank SER area
- Total number of holes
- Total number of bends and forms

aPriori chooses between sets of coefficients to be used in the linear combination based on whether the part requires side actions (that is, whether there are cam bending stations--see the formula below)

The sets of coefficients are derived from large, representative data sets of sample of parts.

Number of Stages =

- Number of Trimming Stages**
- + Number of Piercing Stages**
- + Number of Up Extruding Or Countersinking Stages**
- + Number of Down Extruding Or Countersinking Stages**
- + Number of Bending Up Stages**
- + Number of Bending Down Stages**
- + Number of Cam Bending Stages**
- + Number of Forming Up Stages**
- + Number of Forming Down Stages**
- + Number of Restriking Up Stages**
- + Number of Restriking Down Stages**

The number of stages is the sum of the number of each of the types of stages—see below.

Number of Trimming Stages = {

- 1, if $\text{rounddown}(\text{Blank Perimeter} / \text{Trim Punch Length}) - 1 \leq 1$;**
- 2, if $\text{rounddown}(\text{Blank Perimeter} / \text{Trim Punch Length}) - 1 == 2$;**
- 3, otherwise}**

Trimming stages include trimming, piercing, and scoring operations.

The number of trimming stations depends on the following:

- Blank perimeter length (see the PSO [Perimeter of the flat pattern blank](#))
- Trim punch length (see the formula below)
- Number of edge trimming stations (this is always 1—see above)
- Trim station adder for two out (1 if the number of concurrent parts is 2; 0 otherwise)

Trim Punch Length = {

- typical large trim punch length, for large parts;**
- typical small trim punch length, for small parts;**
- blank perimeter/2, for very small parts}**

Large and small trim punch lengths are 406.4 or 355.6 in aPriori starting point VPEs. They are specified in the lookup table `toolingComponentAttributes`.

Part size (large, small or very small) is determined as follows:

- Large, if blank perimeter (see the PSO [Perimeter of the flat pattern blank](#)) is greater than the cost model variable `upperBlankPerimeterLengthThreshold`.
- Small, if the blank perimeter is between the cost model variables `upperBlankPerimeterLengthThreshold` and `lowerBlankPerimeterLengthThreshold` (but not equal to the lower threshold).
- Very small, if the blank perimeter is less than or equal to the cost model variable `lowerBlankPerimeterLengthThreshold`.

Number of Piercing Stages = {

- 1, if the number of holes is > 50;**
- 0, otherwise}**

Piercing stages include piercing, trimming, and forming operations.

The number of piercing stages is 1 if the PSO [Number of Holes](#) is greater than 50. Otherwise, the number of piercing stations is 0.

Number of UP Extruding or Countersinking Stages = {
1, if both the following hold:
there are up flanged or countersunk holes, and
the number of up bends plus the number of up forms is 0 or 1;
0, otherwise}

Up extruding or countersinking stages include up extruding, countersinking, forming, and bending operations.

The number of up extruding or countersinking stages is 1 if both the following hold:

- PSO Number of UP Flanged or Countersunk Holes is greater than 0.
- PSO Number of UP Forms plus PSO Number of UP Bends is 0 or 1.

Otherwise, the number of up extruding or countersinking stages is 0.

Number of DOWN Extruding or Countersinking Stages = {
1, if both the following hold:
there are down flanged or countersunk holes, and
the number of down bends plus the number of down forms is 0 or 1;
0, otherwise}

Down extruding or countersinking stages include down extruding, countersinking, forming, and bending operations.

The number of down extruding or countersinking stages is 1 if both the following hold:

- PSO Number of DOWN Flanged or Countersunk Holes is greater than 0.
- PSO Number of DOWN Forms plus PSO Number of DOWN Bends is 0 or 1.

Otherwise, the number of down extruding or countersinking stages is 0.

Number of UP Bending Stages = Roundup (Number of UP Bending Operations/2)

Up bending stages include up bending, forming, and restriking operations.

The number of up bending stages is half the number of up bending operations (see the formula below), rounded up to the nearest integer.

Number of UP Bending Operations = Roundup (number of up bends/3)

The number of up bending operations is PSO Number of UP Bends divided by 3, rounded up to the nearest integer.

Number of DOWN Bending Stages = Roundup (Number of DOWN Bending Operations/2)

Down bending stages include down bending, forming, and restriking operations.

The number of down bending stages is half the number of down bending operations (see the formula below), rounded up to the nearest integer.

Number of DOWN Bending Operations = Roundup (number of down bends/3)

The number of up bending operations is PSO Number of DOWN Bends divided by 3, rounded up to the nearest integer.

Number of Cam Bending Stages = {number of bends over 95 degrees}

The number of cam bending stations is the value of the PSO Number of Bends that are Greater than 95 Degrees.

**Number of UP Forming Stages = {
Roundup(Number of UP Forming Operations/4) – Number of UP Bending Stages, if this value > 0;
0, otherwise}**

Up forming stages include up forming, bending, and restriking operations.

The number of UP forming stations is the difference between the following two values, assuming the first value is greater than the second value:

- Number of up forming operations (see the formula below) divided by 4, rounded up to the nearest integer.
- Number of up bending stages—see the formula above.

If the first value is not greater than the second value, the number of UP forming stages is 0.

Number of UP Forming Operations = Roundup (number of up forms/2)

The number of up forming operations is PSO [Number of UP Forms](#) divided by 2, rounded up to the nearest integer.

**Number of DOWN Forming Stages = {
Roundup(Number of DOWN Forming Operations/4) – Number of DOWN Bending Stages, if > 0;
0, otherwise}**

DOWN forming stages include up forming, bending, and restriking operations.

The number of DOWN forming stations is the difference between the following two values, assuming the first value is greater than the second value:

- Number of down forming operations (see the formula below) divided by 4, rounded up to the nearest integer.
- Number of down bending stages—see the formula above.

If the first value is not greater than the second value, the number of DOWN forming stages is 0.

Number of UP Restriking Stages = Roundup (Number of UP Restriking Operations/2)

Up restriking stages include up restriking, bending, and forming operations.

The number of up restriking stages is half the number of up restriking operations (see the formula below), rounded up to the nearest integer.

Number of UP Restriking Operations = Roundup (number of up forms/4)

The number of up restriking operations is PSO [Number of UP Forms](#) divided by 3, rounded up to the nearest integer.

Number of DOWN Restriking Stages = Roundup (Number of Down Restriking Operations/2)

Down restriking stages include down restriking, bending, and forming operations.

The number of down restriking stages is half the number of down restriking operations (see the formula below), rounded up to the nearest integer.

Number of DWON Restriking Operations = Roundup (number of down forms/4)

The number of down restriking operations is PSO Number of DOWN Forms divided by 3, rounded up to the nearest integer.

Additional User Inputs

The following process setup options control the addition of extra space around blanks, between blanks, and between blanks and the coil edge:

- Width of Addendum Added to Blank Size [per side]
- Stock Length Margin
- Stock Width Margin

Width of Addendum Added to Blank Size [per side]

An offset to be added all around the perimeter of the flattened part. You can enter a non-zero value in order to add additional material to the flattened part to account for forms, or for the purpose of holding the blank during the stamping process which is subsequently trimmed away. This value affects machine selection and material utilization.

Select one of the following options:

- No Addendum: this is the default.
- Computed Based on Form Depth: based on lookup by total form depth (see the [PSO Total Depth of Forms](#)) in the lookup table **blankAddendumWidth**.
- User Override: enter a value greater than or equal to 0.

Stock Length Margin

Length to be added to the stock. This value affects machine selection and material utilization.

Select one of the following options:

- Default: value of the cost model variable **lengthMarginStageTooling** (20 mm in aPriori starting point VPEs).
- User Override: enter a value greater than or equal to 0.

Stock Width Margin

Width to be added to the stock. This value affects machine selection and material utilization.

Select one of the following options:

- Default: value of the cost model variable **widthMarginStageTooling** (16 mm in aPriori starting point VPEs).
- User Override: enter a value greater than or equal to 0.

Process Defaults and Thresholds

This section lists some of the important cost model variables and toolshop variables.

widthMarginStageTooling	See Machine Selection .
lengthMarginStageTooling	See Machine Selection .
customCutMultiplier	See Material Cost and Utilization .
cycleTimeAdjustmentFactor	See Cycle Time Calculation .
upperBlankPerimeterLengthThreshold	See Tooling Calculation .
lowerBlankPerimeterLengthThreshold	See Tooling Calculation .

The toolshop variables **Avg Labor Rate** and **Avg Matl Rate** affect tooling costs—see [Tooling Calculation](#).



29 User Guided Sheet Metal—Turret Press

This section describes the costing details and inputs that are available for User Guided Turret Press and the associated Bend Brake process. These processes are part of the User Guided process group for UG Sheet Metal VPEs. See [User Guided Costing](#) for an introduction to user-guided costing.

For this process, aPriori estimates manufacturing times and costs for low-volume sheet metal parts. The routing can include secondary surface treatment and packaging processes (if you have licensed these modules). Since this is not a GCD-driven cost model, cost estimates are not based on a CAD model and geometry extraction; rather, basic geometric inputs (such as blank dimensions and number of bends and forms) are provided by the user. See [Sheet Metal](#) for the GCD-driven stage tooling cost model.

The chapter includes the following sections:

- Cost Model Overview
 - Geometric Inputs
 - Feasibility and Routing
 - Cost Algorithms and Calculations
 - Process Defaults and Thresholds
-

Cost Model Overview

With some notable differences, the user guided stage tooling cost model is based on the same calculations as the GCD-driven cost model for Turret Press found in the Sheet Metal process group.

In general, costs are determined by aggregating material, labor, machine, and tooling costs.

This overview section summarizes assumptions and limitations of the following aspects of the model:

- General Process
- Part Geometry
- Materials
- Machines
- Tooling

General Process

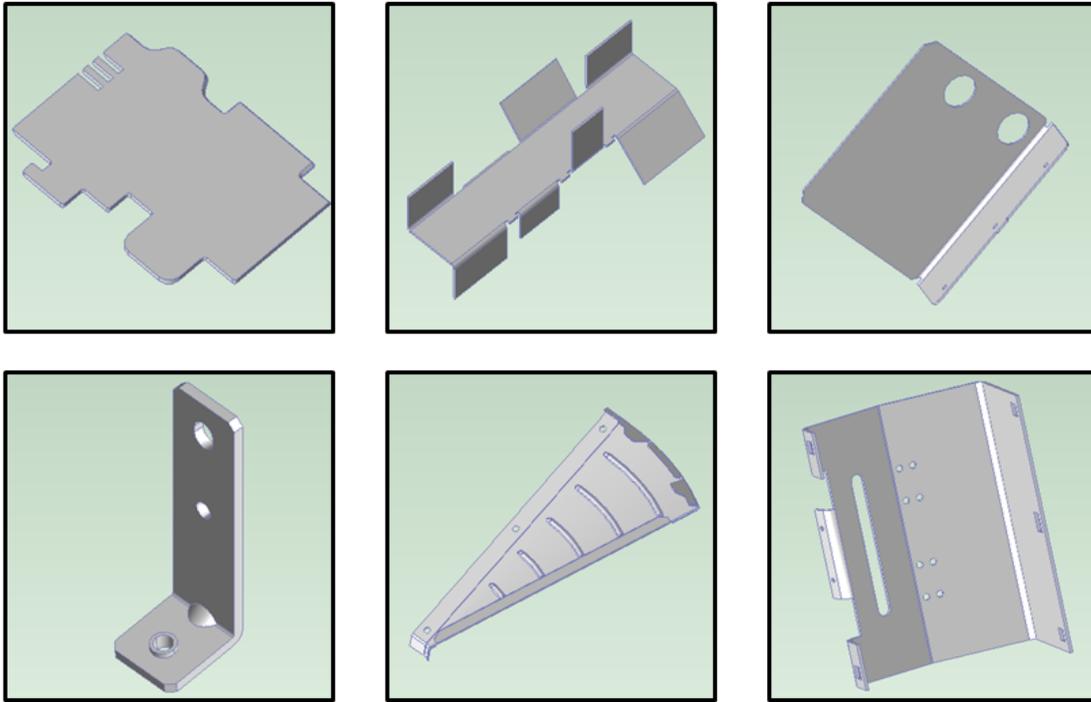
Turret Press is a punching process that supports periphery cutting and hole making for thin (< 10mm) sheet metal. This operation is very slow when cutting thick material. Turret presses are CNC controlled and can be driven mechanically, hydraulically, or with a combination of both. Turret machines are generally large, as they can handle large stock sheets (at least 4' x 8') of metal.

Bend Brake is a sheet metal process used after cutting to create straight or simple curved bends. Bend-brakes can be hand operated or driven (hydraulically or mechanically). This operation cannot form bend radii less than the thickness of the material.

If you have licensed the appropriate modules, your routing can include optional heat treatment, surface treatment, and packaging processes.

Part Geometry

A small selection of example parts is shown below.



Geometry extraction is replaced by geometric inputs in the user guided cost model. For turret press, these inputs include, among others, the following:

- Part volume
- Flat pattern blank dimensions
- Sheet stock dimensions
- Number of bends and forms
- Number of large and small, simple and complex holes
- Number of large and small rounded edges
- Total length of straight edges

See [Geometric Inputs](#) for more information.

Materials

Materials include the following:

- Aluminum: 3003, 5052, 6061
- Copper: 110
- Galvanized Steel: HR-1010, HR-1012, HR-1020
- Stainless Steel: 304, 316, 316L
- Steel: CR-1010, CR-1012, CR-1020, HR-1010, HR-1012, HR-1020

Material composition details include the following:

- Unit Cost (USD / kg)
- Density (kg / m³)
- Shear Strength (MPa)
- Ultimate Tensile Strength (MPa)

Material details include equivalent DIN and EN name standards for use with regional VPEs.

See [Material Selection](#) for more information.

Machines

The following tables list important machine property value ranges. Ranges are listed below for those processes that support a choice of machines:

Turret Press

Property	Low End	High End
Nibble Rate (cycles / min)	420.0	600.0
Punch Rate (cycles / min)	240.0	280.0
Max Sheet Length (mm)	1,260.0	4,978.0
Max Sheet Width (mm)	650.0	1,524.0
Max Punch Size (mm)	88.9	114.3
Press Force (kN)	215.8	490.3

Bend Brake

Property	Low End	High End
Max Bend Length (mm)	415.0	4,267.2
Max Sheet Width (mm)	510.0	3,810.0
Press Force (kN)	75.0	2,373.0

See [Machine Selection](#) for more information.

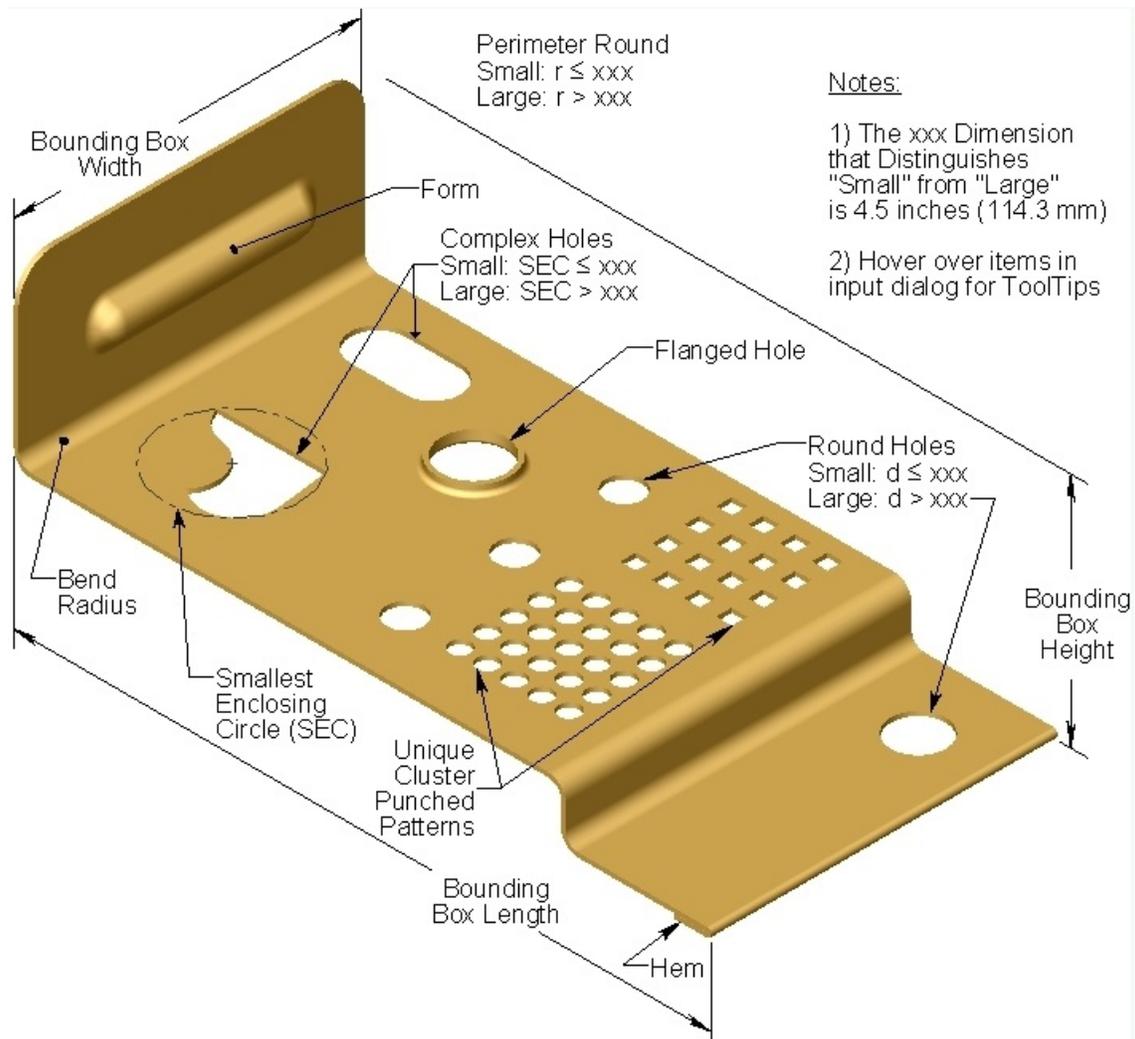
Tooling

Turret Press does not involve hard tooling. Expendable tooling is assumed for flanged and countersunk holes, forms, and perforations—see [Turret Press Expendable Tooling Costs](#).

Geometric Inputs

This section covers the Process Setup Options (PSOs) that serve as substitutes for the geometry extraction performed by GCD-driven cost models.

The following start part image provides an overview of the relevant, user-supplied, geometric values:.



Follow these guidelines to ensure that your part will cost:

- 1 Create a virtual part and use the settings from an appropriate start part (select or search for the start part scenario from the **Recently Used Settings** menu of the Cost Guide's Production Scenario tab—see [Using Settings from a Start Part](#)).
- 2 Open the **User Guided** node in the Process and Machine Options tab of the Cost Guide. Supply a nonzero value for the required PSO Part Volume.
- 3 Open the **Sheet Metal PG** node in the Process and Machine Options tab of the Cost Guide. Supply a nonzero value for all the following required PSOs:
 - o Thickness of Part
 - o Width of the flat pattern's Smallest Enclosing Rectangle
 - o Length of the flat pattern's Smallest Enclosing Rectangle

Ensure that Length of the flat pattern's Smallest Enclosing Rectangle is greater than or equal to Width of the flat pattern's Smallest Enclosing Rectangle.

- 4 If your routing includes surface treatment or other secondary processes, supply nonzero values for all the following PSOs (the **Sheet Metal PG** node):

- Length of the finished part's Bounding Box
- Width of the finished part's Bounding Box
- Height of the finished part's Bounding Box

Ensure that Length of the finished part's Bounding Box is greater than or equal to Width of the finished part's Bounding Box, and that Width of the finished part's Bounding Box is greater than or equal to Height of the finished part's Bounding Box

- 5 If your routing includes surface treatment, supply a non-zero value for the PSO Surface Area of the Part (in the **Sheet Metal PG** node).
- 6 Open the **Turret Press Routing** node. Supply a value that is greater than or equal to 0 for both the required PSOs.
- 7 Open the **Turret Press** node. Supply a value that is greater than or equal to 0 for all the required PSOs; if you or your start part supplies a value greater than 0, also supply *consistent*, nonzero values for the associated, *conditionally* required PSOs. Each required PSO's associated conditionally required PSOs are listed below, together with their consistency requirements.
- 8 In the **Bend Brake** node, supply a value that is greater than or equal to 0 for all the required PSOs.

The following table lists the required PSO's that have associated conditionally required PSOs. The associated conditionally required PSOs are shown, together with their consistency requirements:

Required PSO	Associated Conditionally Required PSO
<ul style="list-style-type: none"> ▪ Number of Small Rounded Sections 	<ul style="list-style-type: none"> ▪ Unique Radii in Number of Small Rounded Sections <p>Ensure that this is less than or equal to Number of Small Rounded Sections.</p>
<ul style="list-style-type: none"> ▪ Number of Large Rounded Sections 	<ul style="list-style-type: none"> ▪ Average Radius of Large Rounded Sections
<ul style="list-style-type: none"> ▪ Number of Small Round Holes 	<ul style="list-style-type: none"> ▪ Unique Radii in Number of Small Round Holes <p>Ensure that this is less than or equal to Number of Small Round Holes.</p>
<ul style="list-style-type: none"> ▪ Number of Large Round Holes 	<ul style="list-style-type: none"> ▪ Average Diameter of Large Round Holes
<ul style="list-style-type: none"> ▪ Number of Small Complex Holes 	<ul style="list-style-type: none"> ▪ Unique Shapes in Number of Small Complex Holes <p>Ensure that this is less than or equal to Number of Small Complex Holes.</p>
<ul style="list-style-type: none"> ▪ Number of Large Complex Holes 	<ul style="list-style-type: none"> ▪ Average Perimeter of Large Complex Holes
<ul style="list-style-type: none"> ▪ Number of Holes Made with Cluster Punches 	<ul style="list-style-type: none"> ▪ Number of Unique Cluster Punches

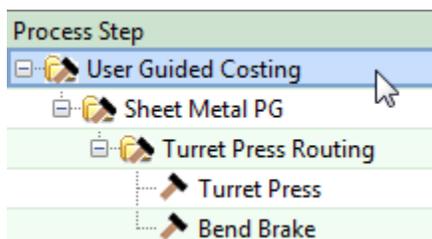
	Ensure that Number of Holes made with Cluster Punches divided by Number of Unique Cluster Punches is greater than or equal to Average Number of pins per Cluster Punch tool (9 by default).
<ul style="list-style-type: none"> Number of Forms 	<ul style="list-style-type: none"> Number of Unique Forms <p>Ensure that this is less than or equal to Number of Forms.</p>
<ul style="list-style-type: none"> Number of Flanged Holes 	<ul style="list-style-type: none"> Number of Uniquely Shaped Flanged Holes <p>Ensure that this is less than or equal to Number of Flanged Holes.</p>
<ul style="list-style-type: none"> Number of Countersunk Holes 	<ul style="list-style-type: none"> Unique Sizes in Number of Countersunk Holes <p>Ensure that this is less than or equal to Number of Countersunk Holes.</p>
<ul style="list-style-type: none"> Number of Tapped Holes 	<ul style="list-style-type: none"> Unique Sizes in Number of Tapped Holes <p>Ensure that this is less than or equal to Number of Tapped Holes.</p>

The geometric input PSOs are associated with various routing nodes. All these PSOs are described in detail in the following sections:

- User Guided Costing Node
- Sheet Metal PG Node
- Turret Press Routing Node
- Turret Press Node
- Bend Brake Node

User Guided Costing Node

The top-level PSO node includes one PSO, which is required. If you do not supply a value for this PSO, the part fails to cost.



Part Volume

Required

Part volume is a required input for all user guided processes. This is the volume of the material that constitutes the part.

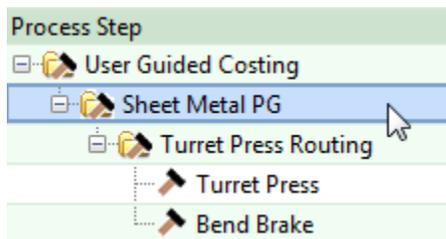
Part volume is used to calculate part mass. Part mass is used in material cost and utilization calculations—see [Turret Press Material Cost and Utilization](#). Part mass also drives handling time, and so contributes to cycle time—see [Turret Press Cycle Time Calculation](#) and [Bend Brake Cycle Time Calculation](#).

***Part Volume** (Piece Part & Tooling Cost Driver)
Used to calculate part mass and various values impacting part and tooling cost
 User Required (≥ 0.000): mm³

Enter a value greater than 0.

Sheet Metal PG Node

The Sheet Metal PG node includes PSOs that apply to all user guided sheet metal parts.



This node includes three required inputs related to the dimensions of the flattened blank:

- Thickness of Part
- Length of the flat pattern's Smallest Enclosing Rectangle
- Width of the flat pattern's Smallest Enclosing Rectangle

***Thickness of Part**
Enter the thickness of the metal used to make the part
 User Required (≥ 0.000): mm

***Length of the flat pattern's Smallest Enclosing Rectangle**
The SER is the smallest rectangle that completely encloses the flat pattern
 User Required (≥ 0.000): mm

***Width of the flat pattern's Smallest Enclosing Rectangle**
The SER is the smallest rectangle that completely encloses the flat pattern
 User Required (≥ 0.000): mm

This node also includes three conditionally required inputs, related to the part dimensions:

- Length of the finished part's Bounding Box
- Width of the finished part's Bounding Box
- Height of the finished part's Bounding Box

****Length of the finished part's Bounding Box**
Length is the longest dimension of the Bounding Box
 User Required(>=0.000): mm

****Width of the finished part's Bounding Box**
Width is the second longest dimension of the Bounding Box
 User Required(>=0.000): mm

****Height of the finished part's Bounding Box**
Height is the shortest dimension of the Bounding Box
 User Required(>=0.000): mm

Finally, there is a conditionally required PSO for surface area:

- Surface Area of the Part

****Surface Area of the Part**
Required if this scenario includes secondary processes
This drives the cost of secondary processes like plating, anodizing, powder coating, etc
 User Override(>=0.000): mm²

Thickness of Part

Required

This is the thickness of the stock used to create the part. This value contributes to material utilization via stock mass (see [Turret Press Material Cost and Utilization](#)), and affects machine selection (see [Turret Press Machine Selection and Bend Brake Machine Selection](#)).

Enter a value greater than 0.

Length of the flat pattern's Smallest Enclosing Rectangle

Required

This is the longer dimension of the flattened part's smallest enclosing rectangle (that is, SER length > SER width). It is used to calculate number of parts per sheet (see [Turret Press Material Cost and Utilization](#)).

Enter a value greater than 0.

Width of the flat pattern's Smallest Enclosing Rectangle

Required

This is the shorter dimension of the flattened part's smallest enclosing rectangle (that is, SER length > SER width). It is used to calculate number of parts per sheet (see [Turret Press Material Cost and Utilization](#)).

Enter a value greater than 0.

Length of the finished part's Bounding Box

Conditionally required; may be required for secondary processes.

This is the longer dimension of the finished part's smallest enclosing box (that is, bounding box length > bounding box width). It may contribute to calculations for secondary processes. A value of 0 is used by default.

Enter a value greater than 0.

Width of the finished part's Bounding Box

Conditionally required; may be required for secondary processes.

This is the shortest dimension of the finished part's smallest enclosing box (that is, bounding box length > bounding box width). It may contribute to calculations for secondary processes. A value of 0 is used by default.

Enter a value greater than 0.

Height of the finished part's Bounding Box

Conditionally required; may be required for secondary processes.

This is the height of the finished part's bounding box—the dimension of the bounding box that is perpendicular to the flat pattern blank. It may contribute to calculations for secondary processes. A value of 0 is used by default.

Enter a value greater than 0.

Surface Area of the Part

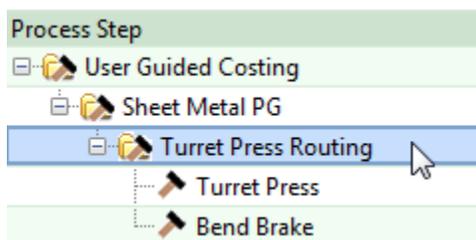
Conditionally required; may be required for secondary processes.

This is the surface area of the material comprising the finished part. It may contribute to calculations for secondary processes. A value of 0 is used by default.

Enter a value greater than 0.

Turret Press Routing Node

The Turret Press Routing node includes required and optional PSOs. If you don't enter a value for a required PSO, the part fails to cost.



The following PSOs are required:

- Number of Bends
- Number of Hemmed Bends

The following PSOs are optional:

- Stock Sheet Length
- Stock Sheet Width
- Part Spacing for Rectangular Nesting

Stock Sheet Length

Optional

This value affects machine selection, material cost and utilization, and cycle time. It is used to calculate stock mass and number of parts per sheet. See [Turret Press Machine Selection](#), [Turret Press Material Cost and Utilization](#), and [Turret Press Cycle Time Calculation](#).

By default, stock sheet length is specified by the cost model variable **defaultSheetLengthTurretPress**. You can override the default and specify a stock sheet length explicitly.

Enter a value greater than 0.

Stock Sheet Width

Optional

This value affects machine selection, material cost and utilization, and cycle time. It is used to calculate stock mass and number of parts per sheet. See [Turret Press Machine Selection](#), [Turret Press Material Cost and Utilization](#), and [Turret Press Cycle Time Calculation](#).

By default, stock sheet length is specified by the cost model variable **defaultSheetWidthTurretPress**. You can override the default and specify a stock sheet length explicitly.

Enter a value greater than 0.

Part Spacing for Rectangular Nesting

Optional

This is the width of the trim strip around parts on a stock sheet. It is used to calculate number of parts per sheet, and affects material utilization (see [Turret Press Material Cost and Utilization](#) and cycle time (via tool change time—see [Turret Press Cycle Time Calculation](#)).

By default this value is 0.

To override the default, enter a value greater than or equal to 0.

Number of Bends

Required

This is the number of bends, *not* including hemmed bends (bends that fold back onto themselves). If bends are present, the Bend Brake process is included in the routing after Turret Press. The number of bends contributes to cycle time—see [Bend Brake Cycle Time Calculation](#).

Enter a value greater than or equal to 0.

Number of Hemmed Bends

Required

This is the number of hemmed bends (bends that fold back onto themselves). If hemmed bends are present, the Bend Brake process is included in the routing after Turret Press.

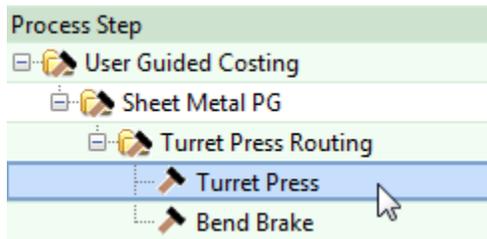
The number of hemmed bends contributes to cycle time—see [Bend Brake Cycle Time Calculation](#).

Enter a value greater than or equal to 0.

Turret Press Node

This node includes required and conditionally required PSOs. A conditionally required PSO is one that is required if you have entered a nonzero value for a particular, related PSO. For example, Average Diameter of Large Round Holes is required if you have entered a nonzero value for Number of Large Round Holes.

If you don't enter a value for a required PSO, the part fails to cost. If you don't enter a value for a conditionally required PSO when its associated condition is met, the part fails to cost.



This section lists the PSOs in this node that act as substitutes for the geometry extraction performed for GCD-driven process groups. Other PSOs associated with this node are listed in [User Inputs](#).

The following PSOs are required:

- Straight Edge Length
- Number of Small Rounded Sections
- Number of Large Rounded Sections
- Number of Small Round Holes
- Number of Large Round Holes
- Number of Small Complex Holes
- Number of Large Complex Holes
- Number of Holes Made with Cluster Punches
- Number of Forms
- Number of Flanged Holes
- Number of Flanged Holes
- Number of Countersunk Holes
- Number of Tapped Holes

The following PSOs are conditionally required:

- Unique Radii in Number of Small Rounded Sections
- Average Radius of Large Rounded Sections
- Unique Radii in Number of Small Round Holes
- Average Diameter of Large Round Holes
- Unique Shapes in Number of Small Complex Holes
- Average Perimeter of Large Complex Holes

- Number of Unique Cluster Punches
- Number of Unique Forms
- Number of Uniquely Shaped Flanged Holes
- Unique Sizes in Number of Countersunk Holes
- Unique Sizes in Number of Tapped Holes

The following PSO is optional:

- Average Number of Pins per Cluster Punch Tool

Straight Edge Length

Required

This is the sum of the lengths of straight edges of the flattened part. This value contributes to punch time (see [Turret Press Cycle Time Calculation](#)).

Enter a value greater than or equal to 0.

Number of Small Rounded Sections

Required

This is the number of small rounded edges of the flattened part. A rounded edge is considered small if its radius is less than or equal to 4.5 inches (114mm).

This value contributes to punch time (see [Turret Press Cycle Time Calculation](#)).

Enter a value greater than or equal to 0.

If you supply a non-zero value for this PSO, you must supply a non-zero value for the PSO [Unique Radii in Number of Small Rounded Sections](#).

Unique Radii in Number of Small Rounded Sections

Conditionally required

If you supply a non-zero value for the PSO [Number of Small Rounded Sections](#), you must supply a non-zero value for this PSO.

This is the number of different radii of small, rounded sections (see [Number of Small Rounded Sections](#)). If all small rounded sections have the same radius, this value is 1; if each small, rounded section has one of two possible radii, this value is 2; and so forth.

This value contributes to the determination of the number of different tools required to make the part, which determines tool change time—see [Turret Press Cycle Time Calculation](#).

Enter a value greater than 0.

Number of Large Rounded Sections

Required

This is the number of large rounded edges of the flattened part. A rounded edge is considered large if its radius is greater than 4.5 inches (114mm).

This value contributes to nibbling time (see [Turret Press Cycle Time Calculation](#)).

Enter a value greater than or equal to 0.

If you supply a non-zero value for this PSO, you must supply a non-zero value for the [PSO Average Radius of Large Rounded Sections](#).

Average Radius of Large Rounded Sections

Conditionally required

If you supply a non-zero value for the [PSO Number of Large Rounded Sections](#), you must supply a non-zero value for this PSO.

This value contributes to the determination of nibbling time (see [Turret Press Cycle Time Calculation](#)).

Enter a value greater than 0.

Number of Small Round Holes

Required

This is the number of circular holes whose radius is less than or equal to 4.5 inches (114mm), including cluster punched round holes, but *excluding* countersunk and flanged holes.

This value contributes to punch time (see [Turret Press Cycle Time Calculation](#)).

Enter a value greater than or equal to 0.

If you supply a non-zero value for this PSO, you must supply a non-zero value for the [PSO Unique Radii in Number of Small Round Holes](#).

Unique Radii in Number of Small Round Holes

Conditionally required

If you supply a non-zero value for the [PSO Number of Small Round Holes](#), you must supply a non-zero value for this PSO.

This is the number of different sizes of small, round holes. If all small holes have the same radius, this value is 1; if each small, round hole has one of two possible radii, this value is 2; and so forth.

This value contributes to the determination of the number of different tools required to make the part, which determines tool change time—see [Turret Press Cycle Time Calculation](#).

Enter a value greater than 0.

Number of Large Round Holes

Required

This is the number of circular holes whose radius is greater than 4.5 inches (114mm). This value contributes to nibbling time (see [Turret Press Cycle Time Calculation](#)).

Enter a value greater than or equal to 0.

If you supply a non-zero value for this PSO, you must supply a non-zero value for the [PSO Average Diameter of Large Round Holes](#).

Average Diameter of Large Round Holes

Conditionally required

If you supply a non-zero value for the PSO [Number of Large Round Holes](#), you must supply a non-zero value for this PSO.

This value contributes to the determination of nibbling time (see [Turret Press Cycle Time Calculation](#)).

Enter a value greater than 9 inches (228mm).

Number of Small Complex Holes

Required

Number of non-circular holes whose smallest enclosing circle has a radius no greater than 4.5 inches (114mm), including cluster-punched, complex holes (see [Number of Holes Made with Cluster Punches](#)), but *excluding* flanged holes.

This value contributes to punch time—see [Turret Press Cycle Time Calculation](#).

If you supply a non-zero value for this PSO, you must supply a non-zero value for the PSO [Unique Shapes in Number of Small Complex Holes](#).

Unique Shapes in Number of Small Complex Holes

Conditionally required

If you supply a non-zero value for the PSO [Number of Small Complex Holes](#), you must supply a non-zero value for this PSO.

This is the number of different shapes that the small complex holes have. It drives the number of punches required, which helps determine tool change time—see [Turret Press Cycle Time Calculation](#).

Number of Large Complex Holes

Required

Number of non-circular holes whose smallest enclosing circle has a radius greater than 4.5 inches (114mm). This value contributes to punch time—see [Turret Press Cycle Time Calculation](#).

If you supply a non-zero value for this PSO, you must supply a non-zero value for the PSO [Average Perimeter of Large Complex Holes](#).

Average Perimeter of Large Complex Holes

Conditionally required

If you supply a non-zero value for the PSO [Number of Large Complex Holes](#), you must supply a non-zero value for this PSO.

Enter a value greater than 358mm.

Number of Holes Made with Cluster Punches

Required

This is the number of small round or small complex holes that are made with cluster punches. It helps determine punch time—see [Turret Press Cycle Time Calculation](#).

Enter a value greater than or equal to 0.

If you supply a non-zero value for this PSO, you must supply a non-zero value for the [PSO Number of Unique Cluster Punches](#).

Number of Unique Cluster Punches

Conditionally required

If you supply a non-zero value for the [PSO Number of Holes Made with Cluster Punches](#), you must supply a non-zero value for this PSO.

This value contributes to setup time (see [Turret Press Accounting Calculations](#)), tool change time (see [Turret Press Cycle Time Calculation](#)), and expendable tooling costs (see [Turret Press Expendable Tooling Costs](#)).

Enter a value greater than 0.

Average Number of Pins per Cluster Punch Tool

Optional

By default, aPriori assumes each cluster punch tool has 9 pins. You can override the default with this PSO.

This value contributes to punch time—see [Turret Press Cycle Time Calculation](#).

Enter a value greater than 0.

Number of Forms

Required

This is the number of forms that need to be created in order to make the part. It affects punch time (see [Turret Press Cycle Time Calculation](#)).

Enter a value greater than or equal to 0.

If you supply a non-zero value for this PSO, you must supply a non-zero value for the [PSO Number of Unique Forms](#).

Number of Unique Forms

Conditionally required

You must enter a value for this PSO if you entered a nonzero value for [Number of Forms](#).

This is the number of different shapes among the part's forms. It specifies the required number of formed punches, and contributes to setup time (see [Turret Press Accounting Calculations](#)), tool change time (see [Turret Press Cycle Time Calculation](#)), and expendable tooling (see [Turret Press Expendable Tooling Costs](#)).

Enter a value greater than 0.

Number of Flanged Holes

Required

This is the number of the part's flanged holes. It affects punch time (see [Turret Press Cycle Time Calculation](#)).

Enter a value greater than or equal to 0.

If you supply a non-zero value for this PSO, you must supply a non-zero value for the [PSO Number of Uniquely Shaped Flanged Holes](#).

Number of Uniquely Shaped Flanged Holes

Conditionally required

You must enter a value for this PSO if you entered a nonzero value for [Number of Flanged Holes](#).

This is the number of different shapes among the part's flanged holes. It specifies the required number of flanged hole punches, and contributes to setup time (see [Turret Press Accounting Calculations](#)), tool change time (see [Turret Press Cycle Time Calculation](#)), and expendable tooling (see [Turret Press Expendable Tooling Costs](#)).

Enter a value greater than 0.

Number of Countersunk Holes

Required

This is the number of the part's countersunk holes. It affects punch time (see [Turret Press Cycle Time Calculation](#)).

Enter a value greater than or equal to 0.

If you supply a non-zero value for this PSO, you must supply a non-zero value for the [PSO Unique Sizes in Number of Countersunk Holes](#).

Unique Sizes in Number of Countersunk Holes

Conditionally required

You must enter a value for this PSO if you entered a nonzero value for [Number of Countersunk Holes](#).

This is the number of different sizes among the part's flanged holes. It determines the required number of specialized punches, and contributes to setup time (see [Turret Press Accounting Calculations](#)), tool change time (see [Turret Press Cycle Time Calculation](#)), and expendable tooling (see [Turret Press Expendable Tooling Costs](#)).

Enter a value greater than 0.

Number of Tapped Holes

Required

This is the number of the part's tapped holes. It affects tapping time (see [Turret Press Cycle Time Calculation](#)).

Enter a value greater than or equal to 0.

If you supply a non-zero value for this PSO, you must supply a non-zero value for the [PSO Unique Sizes in Number of Tapped Holes](#).

Unique Sizes in Number of Tapped Holes

Conditionally required

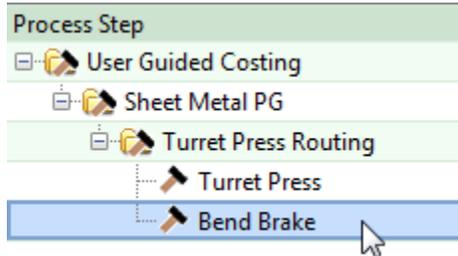
You must enter a value for this PSO if you entered a nonzero value for [Number of Tapped Holes](#).

This is the number of different sizes among the part's tapped holes. It contributes to tool change time (see [Turret Press Cycle Time Calculation](#)).

Enter a value greater than 0.

Bend Brake Node

Bend Brake is included in the routing if the part has hemmed or non-hemmed bends.



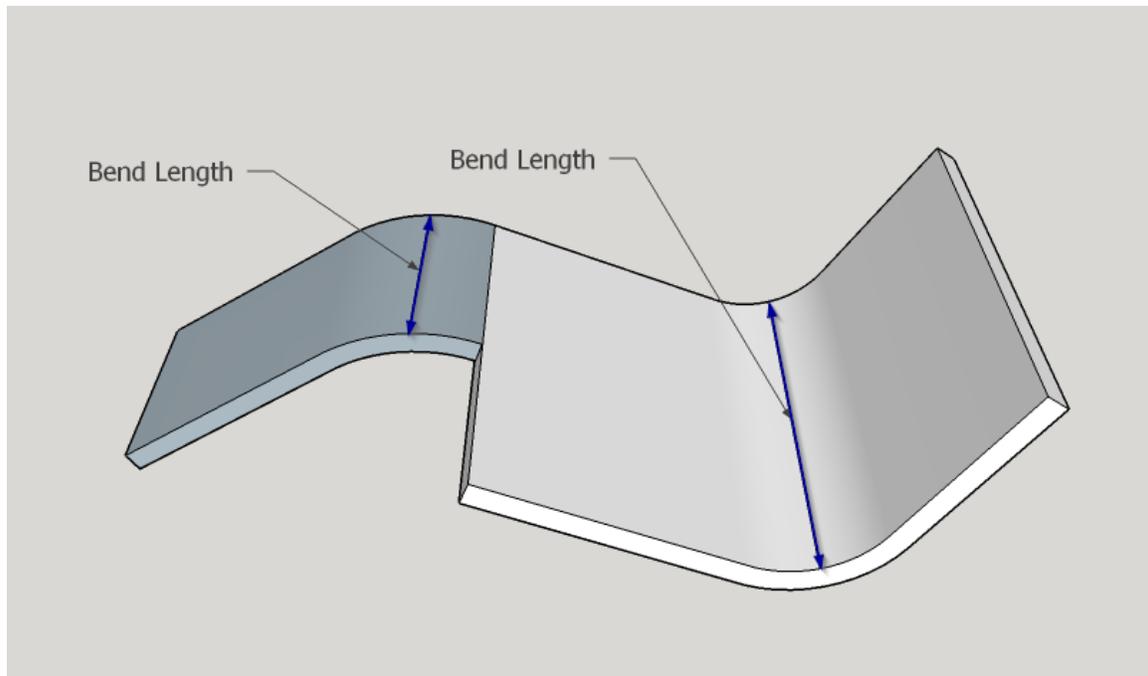
There are three required PSOs:

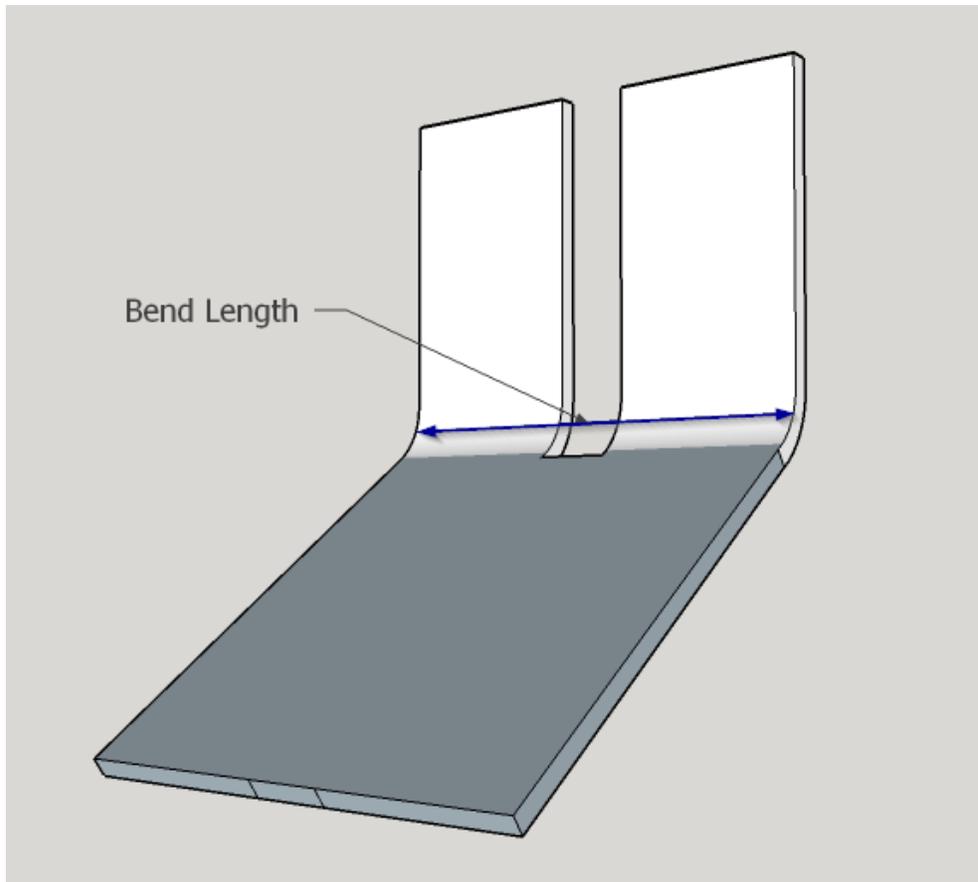
- Maximum Bend Length
- Maximum Bend Radius
- Minimum Bend Radius

Maximum Bend Length

Required

This is the length of the part's longest bend, which affects [Bend Brake Machine Selection](#).





Enter a value greater than 0.

Maximum Bend Radius

Required

This is the part's largest bend radius, which affects [Bend Brake Machine Selection](#).

Enter a value greater than 0.

Minimum Bend Radius

Required

This is the part's smallest bend radius, which affects [Bend Brake Feasibility](#).

Enter a value greater than 0.

Summary Table

Node	PSO	When required	Contributes to
User Guided	Volume	Always required	Material cost Cycle time
Sheet Metal PG	Thickness of Part	Always required	Material cost Machine selection

	Length of the flat pattern's SER	Always required	Material cost
	Width of the flat pattern's SER	Always required	Material cost
	Length of the finished part's bounding box	Required if routing includes secondary process	Secondary process costs
	Width of the finished part's bounding box	Required if routing includes secondary process	Secondary process costs
	Height of the finished part's Bounding Box	Required if routing includes secondary process	Secondary process costs
	Part Surface Area	Required if routing includes Surface Treatment	Surface treatment costs
Turret Press Routing	Stock Sheet Length	Optional—defaults to defaultSheetLengthTurretPress	Material cost Cycle time Machine selection
	Stock Sheet Width	Optional—defaults to defaultSheetWidthTurretPress	Material cost Cycle time Machine selection
	Part Spacing for Rectangular Nesting	Optional—defaults to 0	Material utilization
	Number of Bends	Always required	Cycle time
	Number of Hemmed Bends	Always required	Cycle time
Turret Press	Straight Edge Length	Always required	Punch time
	Number of Small Rounded Sections	Always required	Punch time
	Unique Radii in Number of Small Rounded Sections	Required if Number of Small Rounded Sections > 0	Tool change time
	Number of Large Rounded Sections	Always required	Nibbling time
	Average Radius of Large Rounded Sections	Required if Number of Large Rounded Sections > 0	Nibbling time
	Number of Small Round Holes	Always required	Punch time

Unique Radii in Number of Small Round Holes	Required if Number of Small Round Holes > 0	Tool change time
Number of Large Round Holes	Always required	Nibbling time
Average Diameter of Large Round Holes	Required if Number of Large Round Holes > 0	Nibbling time
Number of Small Complex Holes	Always required	Punch time
Unique Shapes in Number of Small Complex Holes	Required if Number of Small Complex Holes > 0	Tool change time
Number of Large Complex Holes	Always required	Punch time
Average Perimeter of Large Complex Holes	Required if Number of Large Complex Holes > 0	Punch time
Number of Holes Made with Cluster Punches	Always required	Punch time
Number of Unique Cluster Punches	Required if Number of Holes Made with Cluster Punches > 0	Setup time Tool change time Expendable tooling
Average Number of Pins per Cluster Punch Tool	Optional—defaults to 9	Punch time
Number of Forms	Always required	Punch time
Number of Unique Forms	Required if Number of Forms > 0	Setup time Tool change time Expendable tooling
Number of Flanged Holes	Always required	Punch time
Number of Uniquely Shaped Flanged Holes	Required if Number of Flanged Holes > 0	Setup time Tool change time Expendable tooling
Number of Countersunk Holes	Always required	Punch time

	Unique Sizes in Number of Countersunk Holes	Required if Number of Countersunk Holes > 0	Setup time Tool change time Expendable tooling
	Number of Tapped Holes	Always required	Tapping time
	Unique Sizes in Number of Tapped Holes	Required if Number of Tapped Holes > 0	Tool change time
Bend Brake	Maximum Bend Length	Always required	Machine selection
	Maximum Bend Radius	Always required	Machine selection
	Minimum Bend Radius	Always required	Process feasibility

Feasibility and Routing

When you choose the **Sheet Metal** process group, aPriori selects process-level routings, as well as machines and materials. These procedures are described in the following sections:

- Process-level Feasibility
- Material Selection
- Machine Selection

Process-level Feasibility

Process feasibility depends on the values you supply for the geometric PSOs. Turret Press is feasible only if all the following hold:

- You have supplied values for all required PSOs.
- You have supplied nonzero values for all the following PSOs:
 - Part Volume
 - Width of the flat pattern's Smallest Enclosing Rectangle
 - Length of the flat pattern's Smallest Enclosing Rectangle
 - Thickness of the flat pattern's Smallest Enclosing Rectangle
- Length of the flat pattern's SER is greater than or equal to Width of the flat pattern's SER.
- If your routing includes surface treatment, you have supplied a non-zero value for the PSO Surface Area of the Part.
- If your routing includes surface treatment or other secondary processes, you have supplied nonzero values for all the following PSOs:
 - Length of the finished part's Bounding Box
 - Width of the finished part's Bounding Box

- Height of the finished part's Bounding Box
- If your routing includes surface treatment or other secondary processes, both the following hold:
 - Height of finished part's Bounding Box is less than or equal to Width of finished part's Bounding Box
 - Width of finished part's Bounding Box is less than or equal to Length of finished part's Bounding Box.
- For each conditionally required PSO, you have supplied a nonzero value if and only if you have supplied a nonzero value for its associated PSO. For example, you have supplied a nonzero value for total bend length if and only if you have supplied a nonzero value for number of bends.
- If you supplied a value greater than 0 for Number of Small Rounded Sections, you supplied an equal or smaller value for Unique Radii in Number of Small Rounded Sections.
- If you supplied a value greater than 0 for Number of Small Round Holes, you supplied an equal or smaller value for Unique Radii in Number of Small Round Holes.
- If you supplied a value greater than 0 for Number of Holes made with Cluster Punches, then Number of Holes made with Cluster Punches divided by Number of Unique Cluster Punches is greater than or equal to Average Number of pins per Cluster Punch tool (9 by default).
- If you supplied a value greater than 0 for Number of Forms, you supplied an equal or smaller value for Number of Unique Forms.
- If you supplied a value greater than 0 for Number of Flanged Holes, you supplied an equal or smaller value for Number of uniquely shaped Flanged Holes.
- If you supplied a value greater than 0 for Number of Countersunk Holes, you supplied an equal or smaller value for Unique Sized in Number of Countersunk Holes.
- If you supplied a value greater than 0 for Number of Tapped Holes, you supplied an equal or smaller value for Unique Sized in Number of Tapped Holes.

For detailed information on all these PSOs, see [Geometric Inputs](#).

Bend Brake Feasibility

Bend Brake is included in a routing only if one of the following holds:

- Part has hemmed bends (PSO Number of Hemmed Bends is greater than 0).
- Part has bends (PSO Number of Bends is greater than 0)

Bend Brake is feasible only if both the following hold:

- Maximum Bend Radius \geq Minimum Bend Radius.
- Either part has hemmed bends or part's minimum bend radius is not too small.

Minimum bend radius is considered too small if and only if PSO Minimum Bend Radius is greater than or equal to the product of PSO Thickness of Part and cost model variable **minBendRadiusRatio** (0.5 in aPriori baselines).

Material Selection

In direct integration mode with Pro/ENGINEER, if the composition selection mode is **MCAD**, aPriori selects the MCAD composition from the part, if available. Otherwise aPriori selects the VPE default material (Steel, CR-1020).

In CAD-independent mode, aPriori selects the VPE default material (Steel, CR-1020 in aPriori starting point VPEs).

In both direct integration and CAD-independent mode, you can use aPriori's selection or else manually select a material composition and override the material unit cost. To manually specify a material, select **Edit > Material Selection** in the Manufacturing Process pane (see also *Selecting material in Manufacturing Process Information*). You can override the unit cost if desired.

All material stock is virtual stock. Material Stock dimensions are given by the PSOs **Stock Sheet Length**, **Stock Sheet Width**, and **Thickness of Part**.

Machine Selection

The following sections describe machine selection:

- [Turret Press Machine Selection](#)
- [Bend Brake Machine Selection](#)

Turret Press Machine Selection

For Turret Press, aPriori selects the default machine if it is feasible; otherwise, aPriori selects the feasible machine with the lowest overhead (specified by the sum of the machine properties **Direct Overhead Rate** and **Indirect Overhead Rate**).

The machine feasibility rules for turret press require that the machine can accommodate at least the blank for a single part:

- PSO **Stock Sheet Width** must not exceed the machine property **Max Sheet Width**.
- PSO **Stock Sheet Length** must not exceed the machine property **Max Sheet Length**.
- PSO **Thickness of Part** must not exceed the machine property corresponding to the part's material type:
 - **Max Sheet Thickness Steel**
 - **Max Sheet Thickness Aluminum**
 - **Max Sheet Thickness Brass**
 - **Max Sheet Thickness Stainless Steel**
 - **Max Sheet Thickness Copper**

Bend Brake Machine Selection

For Bend Brake, machines are prioritized as follows:

- aPriori selects a feasible machine that can accommodate the length of the part's bends, if such a machine exists. A machine can accommodate the part's bends if and only if the PSO **Maximum Bend Length** does not exceed the machine property **Max Bend Length**.
- If no such machine exists, aPriori selects the default machine, if it is feasible.

- If the default machine is not feasible, aPriori selects the feasible machine with the lowest overhead (specified by the sum of the machine properties **Direct Overhead Rate** and **Indirect Overhead Rate**).

The machine feasibility rules for bend brake require that the machine can accommodate stock sheet thickness as well as the radii (relative to sheet thickness) of the part's bends:

- PSO **Thickness of Part** must not exceed the machine property corresponding to the part's material type:
 - **Max Sheet Thickness Steel**
 - **Max Sheet Thickness Aluminum**
 - **Max Sheet Thickness Brass**
 - **Max Sheet Thickness Stainless Steel**
 - **Max Sheet Thickness Copper**
- Ratio of PSO **Maximum Bend Radius** to PSO **Thickness of Part** does not exceed machine property **Max Radius-to-Thickness Ratio**.

Cost Algorithms and Calculations

This section details how costs are calculated by aPriori. Note that you can override the calculation of many of the quantities involved, and specify them explicitly—see [User Inputs](#), below.

This section covers formulas in the following areas:

- Yields
- Turret Press Material Cost and Utilization
- Turret Press Accounting Calculations
- Bend Brake Accounting Calculations
- Turret Press Cycle Time Calculation
- Turret Press Expendable Tooling Costs
- Bend Brake Cycle Time Calculation

Yields

These formulas are used by both Turret Press and Bend Brake.

Final Yield = Final Output Volume / Input Volume

Final yield affects material, labor, and overhead costs per part. It is the fraction of parts created by this process in the current production scenario that will survive as good parts once any secondary processes are completed. That is, final yield is the fraction of parts created by this process that are *not* discarded as scrap parts, either by this process or by a downstream process. Final yield depends on the following:

- Final Output Volume (product of the annual volume and number of production years, specified in the Production Scenario screen of the Cost Guide)
- Input volume (see the formula below). This is the total number of parts produced by this process, including all parts discarded as scrap from this process or downstream processes.

Input Volume = Local Output Volume + Number of Scrap Parts for This Process

Input volume is the total number of parts produced by this process in the current scenario, including all parts discarded as scrap from this process or downstream processes. It is the sum of the following:

- Local output volume (see the formula below). This is the number of parts produced by this process, excluding parts discarded as scrap by this process, but including parts that are discarded as scrap by downstream processes.
- Number of scrap parts for this process (see the formula below)

Local Output Volume = Final Output Volume + Number of Scrap Parts Downstream

Local output volume is the number of parts produced by this process in the current scenario, excluding parts discarded as scrap by this process, but including parts that are discarded as scrap by downstream processes. It is the sum of the following:

- Final output volume (product of volume and number of production years, specified in the Production Scenario screen of the Cost Guide)
- Number of Scrap Parts Downstream. This is the number of parts discarded as scrap by downstream processes.

**Number of Scrap Parts for This Process =
(Local Output Volume / Good Part Yield) – Local Output Volume**

Number of scrap parts for this process is the number of parts produced by this process in the current scenario that are discarded as scrap by this process, before any downstream process is performed on them. It is a function of the following:

- Local output volume (see the formula above)
- Good part yield (specified by the machine property **Good Part Yield**). This is the fraction of parts produced by this process that are not discarded as scrap by this process but may be discarded as scrap by downstream processes.

Turret Press Material Cost and Utilization

Material Cost = ((Material Cost Per Mass * Part Mass) / Utilization) / Final Yield

aPriori calculates the cost for material based on the following factors:

- Material cost per mass (determined from **Material Stock** if stock is selected; otherwise, from **Material Composition** in the **Material Selection** dialog)
- Part mass (product of part volume and material density—see the **Part Volume** PSO and the **Density** property in the Materials table)
- Utilization (see formula below)
- Final Yield (see **Yields**)

Utilization = Part Mass * Number of Parts per Sheet / Stock Mass

Utilization depends on the following:

- Part mass (product of part volume and material density—see the **Part Volume** PSO and the **Density** property in the Materials table)
- Number of parts per sheet (see below)
- Stock mass (see formula below)

Number of Parts per Sheet

aPriori calculates this value by finding the maximum number of parts that can fit on a sheet of stock, with the parts oriented either lengthwise or widthwise. It takes into account the following measurements:

- Blank SER dimensions (see **Width of the flat pattern's Smallest Enclosing Rectangle** and **Length of the flat pattern's Smallest Enclosing Rectangle**)
- Part spacing. This is specified by the PSO **Part Spacing for Rectangular Nesting**. If the PSO is not supplied, the machine property **Part Spacing** is used. If the PSO is not supplied and the machine property is not present, the cost model variable **rectangularPartSpacing** is used.
- Sheet dimensions (see **Stock Sheet Length** and **Stock Sheet Width**)
- Sheet lengthwise margin (trim strip width specified by the machine property **Sheet Length Trim Strip**)
- Sheet widthwise margin (trim strip width specified by the machine property **Sheet Width Trim Strip**)

Stock Mass = Stock Length * Stock Width * Stock Thickness * Material Density

Stock mass is the product of the following:

- Stock length (specified by the cost model variable **defaultSheetLengthTurretPress**, or the PSO [Stock Sheet Length](#))
- Stock Width (specified by the cost model variable **defaultSheetWidthTurretPress**, or the PSO [Stock Sheet Width](#))
- Stock thickness (specified by the PSO [Thickness of Part](#))
- Material density (specified by the **Density** property in the Materials table)

Turret Press Accounting Calculations

Labor Cost = Labor Time * Labor Rate / Final Yield

Labor cost is a function of the following:

- Labor time (see formula below)
- Labor rate (specified by the machine property **Labor Rate**)
- Final yield (see the formula above)

Labor Time = Cycle Time * Labor Time Standard * Number of Operators

Labor time is the product of the following

- Cycle time (see the formula below)
- Labor time standard (specified as a machine property). This value reflects the amount of time spent by machine operators in between machine cycles, including time performing maintenance and cleaning tasks as well as time pausing between tasks. The amount is expressed as a cycle time multiplier.
- Number of operators (specified by the machine property **Number of Operators**)

Amortized Batch Setup =

(Setup Time Per Batch * (Labor Rate + Direct Overhead Rate)) / Batch Size

Amortized batch setup, setup cost per part, depends on the following:

- Setup time per batch (see formula below)
- Labor rate (specified by the machine property **Labor Rate**)
- Direct overhead rate (see [Direct and Indirect Overhead](#))
- Batch size (specified in the **Production Scenario** screen of the Cost Guide)

Setup Time Per Batch = (Number of Turret Setups * Machine Setup Time) + (Number of Special Tools * Special Tool Setup Time)

Setup time per batch depends on the following:

- Number of turret setups (product of number of tools—see [Turret Press Cycle Time Calculation](#)—and machine property **Number of Tool Stations**)
- Machine setup time (specified by the machine property **Setup Time**)
- Number of special tools (sum of the following PSOs: [Unique Sizes in Number of Countersunk Holes](#), [Number of Unique Forms](#), [Number of Uniquely Shaped Flanged Holes](#), and [Number of Unique Cluster Punches](#))
- Special tool setup time (specified by the machine property **Special Tool Setup**)

Bend Brake Accounting Calculations

Labor Cost = Labor Time * Labor Rate / Final Yield

Labor cost is a function of the following:

- Labor time (see formula below)
- Labor rate (specified by the machine property **Labor Rate**)
- Final yield (see the formula above)

Labor Time = Cycle Time * Labor Time Standard * Number of Operators

Labor time is the product of the following

- Cycle time (see the formula below)
- Labor time standard (specified as a machine property). This value reflects the amount of time spent by machine operators in between machine cycles, including time performing maintenance and cleaning tasks as well as time pausing between tasks. The amount is expressed as a cycle time multiplier.
- Number of operators (specified by the machine property **Number of Operators**)

Amortized Batch Setup = (Setup Time * (Labor Rate + Direct Overhead Rate)) / Batch Size

Amortized batch setup, setup cost per part, depends on the following:

- Setup time per batch (specified by the machine property **Setup Time**)
- Labor rate (specified by the machine property **Labor Rate**)
- Direct overhead rate (see [Direct and Indirect Overhead](#))
- Batch size (specified in the **Production Scenario** screen of the Cost Guide)

Turret Press Cycle Time Calculation

Cycle Time = (Press Cycle Time + Labor Handling Time) * Adjustment Factor

Cycle time is a function of the following:

- Press cycle time (specified by the machine property **Press Cycle Time**)
- Labor handling time (looked up by part mass in the lookup table **smGenericPressHandling**—where part mass is the product of material density and [Part Volume](#))
- Adjustment factor (specified by the cost model variable **cycleTimeAdjustmentFactor**). This factor is 1 in aPiori starting point VPEs. VPE administrators can modify **cycleTimeAdjustmentFactor** in order to adjust cycle times across all processes within the current VPE.

Process Time = Total Punch Time + Total Nibbling Time + Total Tapping Time + Labor Handling Time + Total Tool Change Time

Process time is the sum of the following:

- Total punch time (see formula below)
- Total nibbling time (nibbling is assumed for large features--see formula below)
- Total tapping time (see formula below)
- Labor handling time (looked up by part mass—part volume over material density--in the lookup table **smTurretPressHandling**)
- Total tool change time (see formula below)

$$\text{Total Punch Time} = \frac{(\text{Number of Punched Internal Hits} + \text{Number of Punched External Hits})}{\text{Machine Punching Rate}}$$

Total punch time depends on the following:

- Number of punched internal hits (see formula below)
- Number of punched external hits (see formula below)
- Machine punching rate. This is specified in cycles per minute by the machine property **Punch Rate**. aPriori converts this value to cycles per second for use in this formula.

$$\begin{aligned} \text{Number of Punched Internal Hits} = & \\ & \text{Internal Countersink Hits} + \\ & \text{Form Hits} + \\ & \text{Large Slot Straight Edge Hits} + \\ & \text{Small Slot and Circled Hole Hits} + \\ & \text{Perforation Hits} \end{aligned}$$

Number of punched internal hits is the sum of the following:

- Internal countersink hits (specified by the PSO [Number of Countersunk Holes](#))
- Punched form hits (sum of the PSOs [Number of Forms](#) and [Number of Flanged Holes](#))
- Punched large slot straight edge hits (see formula below)
- Small slot and circled hole hits (see formula below)
- Perforation hits (PSO [Number of Holes Made with Cluster Punches](#) divided by PSO [Average Number of Pins per Cluster Punch Tool](#))

$$\text{Large Slot Straight Edge Hits} = \text{roundup} \left(\frac{\text{Total Large Slot Straight Edge Length}}{\text{Best Internal Tool Size}} \right)$$

Large slot straight edge hits is the quotient (rounded up to the nearest integer) of the following:

- Total large slot straight edge length (product of the PSOs [Number of Large Complex Holes](#) and [Average Perimeter of Large Complex Holes](#))
- Best internal tool size (see below)

Best Internal Tool Size

aPriori chooses the largest tool that will fit a representative slot edge without excess overlap, based on the following values:

- Representative slot edge length, estimated as one quarter of the PSO [Average Perimeter of Large Complex Holes](#)
- Maximum tool overlap, specified by the machine property **Max Tool Overlap**
- Candidate tool sizes, specified by the machine properties **Straight Length, 1** through **Straight Length, 5**

$$\text{Small Slot and Circled Hole Hits} = \text{Small Slot Count} + \text{Small Circled Hole Count} - \text{Perforated Hole Count}$$

The number of small slot and circled hole hits is a function of the following:

- Small slot count (specified by the PSO [Number of Small Complex Holes](#))
- Small circled hole count (specified by the PSO [Number of Small Round Holes](#))

- Perforated hole count (specified by the PSO Number of Holes Made with Cluster Punches)

Number of Punched External Hits = Straight Blank Edge Hits + Small Round Blank Edge Hits

Number of punched external hits is the sum of the following:

- Straight blank edge hits (see formula below)
- Small round blank edge hits (specified by the PSO Number of Small Rounded Sections)

Straight Blank Edge Hits = roundup (Total Straight Blank Edge Length / Best External Tool Size)

Straight blank edge hits is the quotient (rounded up to the nearest integer) of the following:

- Total straight blank edge length (specified by the PSO Straight Edge Length)
- Best external tool size (see below)

Best External Tool Size

aPriori chooses the largest tool that will fit a representative straight blank edge without excess overlap, based on the following values:

- Representative blank edge length, estimated as one quarter of the PSO Straight Edge Length
- Maximum tool overlap, specified by the machine property **Max Tool Overlap**
- Candidate tool sizes, specified by the machine properties **Straight Length, 1** through **Straight Length, 5**

Total Nibbling Time = (Number of Nibbled Internal Hits + Number of Nibbled External Hits) / Machine Nibbling Rate

Nibbling is assumed for large round features. Total nibbling time depends on the following:

- Number of nibbled internal hits (see formula below)
- Number of nibbled external hits (see formula below)
- Machine nibbling rate. This is specified in cycles per minute by the machine property **Nibble Rate**. aPriori converts this value to cycles per second for use in this formula.

Number of Nibbled Internal Hits = roundup (Large Round Hole Nibble Length / (Nibble Tool Diameter – Nibble Tool Overlap * Nibble Tool Diameter))

Number of nibbled internal hits is a function of the following:

- Large round hole nibble length (product of the PSOs **Number of Large Round Holes** and **Average Diameter of Large Round Holes**)
- Nibble tool diameter (specified by the machine property **Nibble Tool Diameter**)
- Nibble tool overlap. This is the fraction of the nibble tool diameter that should overlap the previously nibbled portion, specified by the machine property **Nibble Tool Overlap**.

Number of Nibbled External Hits = roundup (Large Round Edge Length / (Nibble Tool Diameter – Nibble Tool Overlap * Nibble Tool Diameter))

Number of nibbled external hits is a function of the following:

- Large round edge length (product of the PSOs [Number of Large Rounded Sections](#) and [Average Radius of Large Rounded Sections](#))
- Nibble tool diameter (specified by the machine property **Nibble Tool Diameter**)
- Nibble tool overlap. This is the fraction of the nibble tool diameter that should overlap the previously nibbled portion, specified by the machine property **Nibble Tool Overlap**.

Total Tapping Time = Hits Total Tapped Internal / Machine Tapping Rate

Total tapping time is the quotient of the following:

- Hits total tapped internal (specified by the PSO [Number of Tapped Holes](#))
- Machine tapping rate (the machine property **Nibble Rate** divided by the cost model variable **tappingRateReduction**)

Tool Change Time =Number of Tools * Tool Change Time / Number of Parts per Sheet

Tool change time depends on the following:

- Number of tools (see formula below)
- Tool change time (time to change one tool, specified by the machine property **Tool Change Time**)
- Number of parts per sheet (see [Turret Press Material Cost and Utilization](#))

**Number of Tools =
Number of Small Hole Tools +
Number of Countersunk Hole Tools +
Number of Form Tools +
Number of Nibbling Tools +
Number of Curved Blank Edge Tools +
Number of Straight Edge Tools +
Number of Perforation Tools +
Number of Tapping Tools**

Number of tools is the sum of the following:

- Number of small hole tools (sum of the PSOs [Unique Radii in Number of Small Round Holes](#) and [Unique Shapes in Number of Small Complex Holes](#))
- Number of countersunk hole tools (specified by the PSO [Unique Sizes in Number of Countersunk Holes](#))
- Number of form tools (sum of the PSOs [Number of Unique Forms](#) and [Number of Uniquely Shaped Flanged Holes](#))
- Number of nibbling tools (1 if there are large round holes or large curved blank edges; 0 otherwise—see [Number of Large Round Holes](#) and [Number of Large Rounded Sections](#).)
- Number of curved blank edge tools (specified by the PSO [Unique Radii in Number of Small Rounded Sections](#))

- Number of Straight Edge Tools (1 if there are straight blank edges or large complex holes; 0 otherwise—see [Straight Edge Length](#) and [Number of Large Complex Holes](#))
- Number of Perforation Tools (specified by the PSO [Number of Unique Cluster Punches](#))
- Number of tapping tools (specified by the PSO [Unique Sizes](#) in [Number of Tapped Holes](#))

Turret Press Expendable Tooling Costs

Expendable Tooling Costs =

$$\begin{aligned} & (\text{Average Cost for Countersink Tool} * \text{Number of Countersink Tools}) + \\ & (\text{Average Cost for Form Tool} * \text{Number of Form Tools}) + \\ & (\text{Average Cost for Perforation Tool} * \text{Number of Perforation Tools}) \end{aligned}$$

Expendable tooling costs depend on the following:

- Average cost for countersink tool (specified by the machine property **C'sink Tool, Avg Cost**)
- Number of countersink tools (specified by the PSO [Unique Sizes](#) in [Number of Countersunk Holes](#))
- Average cost for form tool (specified by the machine property **Form Tool, Avg Cost**)
- Number of form tools (sum of the PSOs [Number of Unique Forms](#) and [Number of Uniquely Shaped Flanged Holes](#))
- Average cost for perforation tool (specified by the machine property **Perf Tool, Avg Cost**)
- Number of perforation tools (specified by the PSO [Number of Unique Cluster Punches](#))

Bend Brake Cycle Time Calculation

$$\text{Cycle Time} = (\text{Bending Cycle Time} + (\text{Load Time} - \text{Manipulation Time per Bend})) * \text{Adjustment Factor}$$

Cycle time is a function of the following:

- Bending cycle time (see formula below)
- Load time (looked up by part mass in the lookup table **smBendBrakeHandling**—where part mass is the product of material density and [Part Volume](#))
- Manipulation time per bend (looked up by part mass in the lookup table **smBendBrakeHandling**). This value is subtracted to prevent the manipulation time for the first bend from being counted twice. This is necessary because bending cycle time includes manipulation time for every bend (see formula below), and load time includes manipulation time for the first bend.
- Adjustment factor (specified by the cost model variable **cycleTimeAdjustmentFactor**). This factor is 1 in aPiori starting point VPEs. VPE administrators can modify **cycleTimeAdjustmentFactor** in order to adjust cycle $\text{numBendOperations} * (\text{machine.bendCycleTime} + \text{manipulationTimePerBend})$ times across all processes within the current VPE.

Bending Cycle Time = Number of Bend Operations * (Bend Cycle Time + Manipulation Time Per Bend)

Bending cycle time depends on the following:

- Number of bend operations (sum of the PSOs **Number of Bends** and **Number of Hemmed Bends**)
- Bend cycle time for a single bend (specified by the machine property **Bend Cycle Time**)
- Manipulation time per bend (looked up by part mass in the lookup table **smBendBrakeHandling**)

Process Defaults and Thresholds

This section lists some of the important cost model variables and toolshop variables.

rectangularPartSpacing	See Turret Press Material Cost and Utilization.
customCutMultiplier	See Turret Press Material Cost and Utilization.
cycleTimeAdjustmentFactor	See Turret Press Cycle Time Calculation and Bend Brake Cycle Time Calculation.
defaultSheetLength	See Turret Press Material Cost and Utilization.
defaultSheetWidth	See Turret Press Material Cost and Utilization.
minBendRadiusRatio	See Process-level Feasibility.



30 Wire Harness Process Group

This section describes aPriori's capabilities for costing wire harnesses.

Note: This chapter should currently be used only as an overview and reference. aPriori Professional Services has worked with your aPriori administrators to develop customized procedures for your specific company. You should use the documentation that they have provided, along with the most recent wire harness release notes as your primary source of information for costing wire harnesses with aPriori.

This chapter includes the following topics:

- Cost Model Overview
 - To import and cost a new wire harness
 - Cost Algorithms and Calculations
 - User Inputs
 - Process Defaults and Thresholds
-

Cost Model Overview

The aPriori Wire Harness Process Group provides the ability to automatically cost wire harnesses of moderate complexity .

To do this, aPriori requires three simple inputs:

- Outputs from your wire harness design tool in a standardized, .csv format.
- A component type identifier for each part number, such as "Termination", "Wire", "Connector", etc.
- Standard prices for purchased components, wires, braids, etc. This is typically in the form of a Component Library that is set up by an aPriori administrator, mapping Customer Part Numbers and Manufacturer Part Numbers.

If you are an engineer designing a wire harness, you can generate your drawings and then generate .csv output tables to check your costs immediately, allowing you to make design decisions now rather than weeks later when receiving supplier quotes.

If you work in purchasing, you can analyze your wire harness costs at a component level, and start to negotiate from a more knowledgeable position with your suppliers.

Note: The separately-licensed Wire Harness Process Group is somewhat different than other aPriori process groups: it is implemented as a VPE that your administrator(s) import and configure for the users at your site. This VPE consists of two process groups that have been customized for wire harness costing: Assembly, and User Guided. aPriori also provides a "transformation utility" for converting the output from your wire harness design system into a consistent format that can be read by aPriori. You do not really need to be concerned with these architectural details, since aPriori configures the Wire Harness cost model specifically for your company, and provides an easy-to-use interface to walk you through the costing process.

Wire harnesses are considered a type of assembly, but geometric cost drivers (GCDs) are not available the same way they would be for CAD model-based components. Cost drivers are provided via attributes from standard wire harness definition tables

Instead of depending on CAD model GCDs, aPriori extracts cost driver information from standard tables generated by the wire harness design tools, typically in the form of ".csv" files. Users augment the information from these imported files with user-guided data, and with component library information. Most components will be off-the-shelf parts, but we know that many companies specify internal part numbers rather than manufacturer or distributor part numbers. To associate information from the tables to the purchased component information, aPriori Professional Services first maps your internal part numbers to manufacturer or distributor part numbers in a Component Library in the VPE.

This chapter covers day-to-day costing operations and assumes that aPriori Professional Services has worked with your administrators to set up and configure this cost model, including the Component Library. See the aPriori *System Administration Guide* and *VPE Administration Guide* for more information about configuration and maintenance of the Wire Harness and PCBA environments.

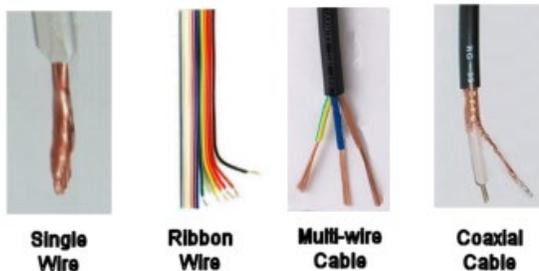
aPriori does not make any assumptions about which specific wire harness design tool is being used: it could range from a standard CAD tool such as PTC Pro/ENGINEER, to a

dedicated wire harness tool such as Zuken E3.series, to a drawing tool such as AutoCAD. The one assumption that we do make is that each of these tools can output most of the inputs that aPriori requires, into a consistent .csv table format. aPriori takes these tables and processes them through a data transformation tool which creates a spreadsheet that can be read by the aPriori BOM loader for the Wire Harness process group.

General Process

Wire harnesses are assemblies that consist of mostly purchased components with minimal processing required. These components can include:

- Wires, which are purchased in bulk lengths and cut and stripped as needed on a component by component basis (wire by wire basis). These can include -- but are not limited to -- the examples shown below:



- Dressing materials and labels, such as tape, bundling materials, insulation, etc., which are purchased and processed in a similar fashion. Examples of dressing materials can include:



- Connectors, pins, terminals, seals, and everything that goes on the ends of a wire harness. These components are typically purchased as-is and just assembled. A few connector examples include:



For a wire harness with normal complexity, aPriori costs the following steps:

- Preparation of the wires and cables. This step includes cutting the wires or cables to length. Also, some additional operations may be carried out such as marking, sealing, molding, sleeving, or labeling of the wires or connectors.

- 2 Assembly of the harness on a board or jig. This includes manually laying-in the wires and cables, inserting the wire ends into connectors if necessary, tying, or taping the bundles or wires and/or sleeving the bundles. Testing is usually done at this stage and some labeling may also be carried out.

Note: aPiori does not currently cost installation of the interconnections or the cable harness into the chassis or product.

Component Types

aPriori recognizes the following wire harness component types and subtypes:

Description	Type	Subtype	Sub-Subtype
Wire	W	W1 -- Single Conductor Stranded Insulated Wire W2 -- Single Conductor Solid Insulated Wire W3 -- Multi-Conductor Cable W4 -- Coax Cable W5 -- Triax Cable W6 -- Ribbon Cable W7 -- Solid Buss	
Terminations	T	T1 -- Contacts T2 -- Ring/Fork/Blade Terminals T3 -- Tinned Wires T4 -- Shield Terminators T5 -- Wire Ferrules	T1A Crimped T1B Soldered T2A Crimped T2AA Machine Crimped T2AM Manually Crimped T2B Soldered T4A Crimped T4B Soldered T5A Machine Crimped T5M Manually Crimped
Connectors	C	C1 -- Unloaded Connectors (default) C2 -- Loaded Connectors C3 -- Ribbon Cable Connectors C4 -- Coax Connectors C5 -- Triax Connectors C6 -- Wedge Locks C7 -- Backshells C8 -- Strain Reliefs C9 -- Dust Caps C10 -- Shrink Boots	
Splices	P	P1 -- Ultrasonic Welds P2 -- Butt Splices P3 -- Insulation Displacement Splices	
Dressing	D	D1 -- Cable Ties D2 -- Seal Tape D3 -- Braid D4 -- Heat Shrink Tubing D5 -- Single Braided Sleeving D6 -- Double Braided Sleeving	

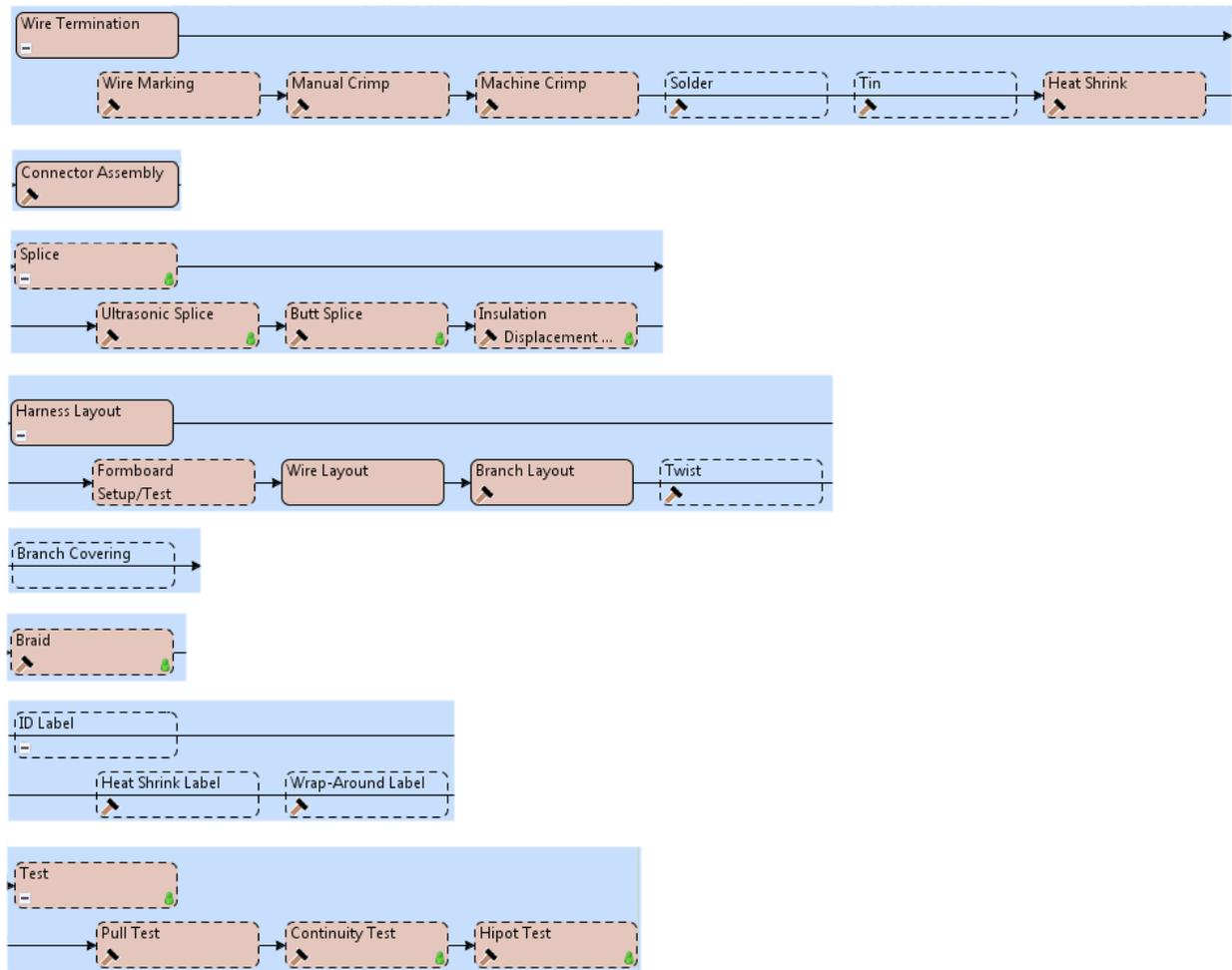
		D7 -- Expando Braided Sleeving D8 -- Split Loom Tubing D9 -- Plain Flexible Conduit D10 -- Liquid Tight Conduit D11 -- Spiral Wrap D12 -- EMI Braiding	
Labels	L	L1 -- Heat Shrink Labels L2 -- Wrap-Around Labels	
Seals	S	S1 -- Plugs S2 -- Wire Seals	
Bundles	B		
Twists	TW		

Routings

The User Guided Process Group for wire harness consists of the following routings based on the above component types:

- Wire Prep (Component Cost, Cut, Strip) - For type Wire (W).
- Dressing Prep (Component Cost, Cut) - For type Dressing (D), either individual or applied to Bundles or Splices.
- No Prep (Component Cost only) - For all remaining types.

The Assembly Process Group routing for wire harness are summarized in the following illustration:



Cost Driver Extraction

Your wire harness design tool must output some or all of the following tables in .csv format. aPriori extracts cost driver information about a wire harness from these tables, which serve as input to the aPriori Transformation Utility (see the next section).

Table Name	Comments	Contains
BOM	Required. (Should not be confused with the BOM generated by the transformation utility for the aPriori BOM loader.)	An itemized list and quantity for each component that appears in the wire harness. Required columns are: Part Number (internal) Quantity
<i>Wire Table</i> (aka <i>Circuit Data Table</i> , <i>Wire Cut List</i>)	Optional	Information about all of the wires in the wire harness including: <ul style="list-style-type: none"> ▪ Wire ID number (reference to schematic) ▪ Length ▪ Gauge

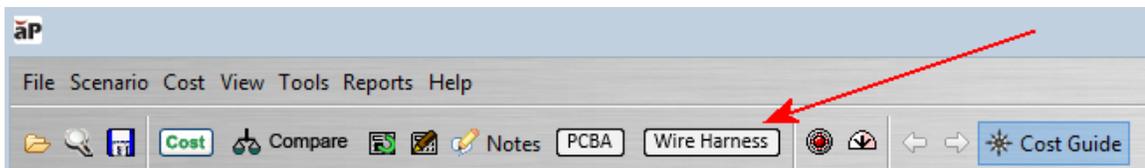
		<ul style="list-style-type: none"> ▪ Color
BUNDLE	Optional Provides cost granularity	Information about all of the bundles in the wire harness, such as: <ul style="list-style-type: none"> ▪ Bundle ID number (reference to schematic) ▪ Bundle diameter ▪ Bundle length ▪ Dressing material part number
SPLICE	Optional Provides cost granularity	Information about all of the splices in the wire harness, such as: <ul style="list-style-type: none"> ▪ Splice ID Number (reference to schematic) ▪ Involved wire information ▪ Insulation part number ▪ Insulation length
TWIST	Optional Provides cost granularity	Information about all of the twists in the wire harness, such as: <ul style="list-style-type: none"> ▪ Twist ID number (reference to schematic) ▪ Involved wire IDs

The information from the tables above contain almost all of the information that aPriori needs to develop a complete cost.

To import and cost a new wire harness

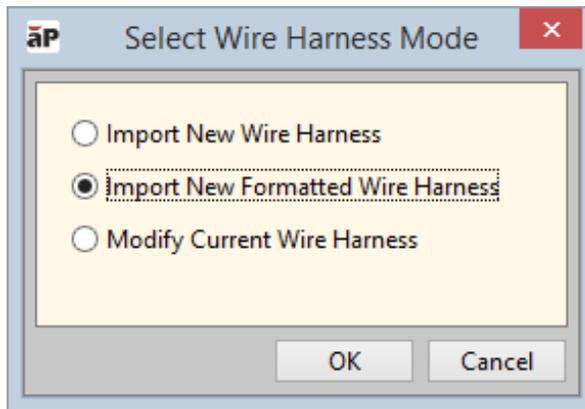
This section provides only a general, high-level summary of the steps you typically follow when costing a wire harness. Your administrators and aPriori Professional Services have worked together to provide procedures specific to your company. You should use the documentation for these customized procedures as your primary source of information.

- 1 In the aPriori client, click the **Wire Harness** button.



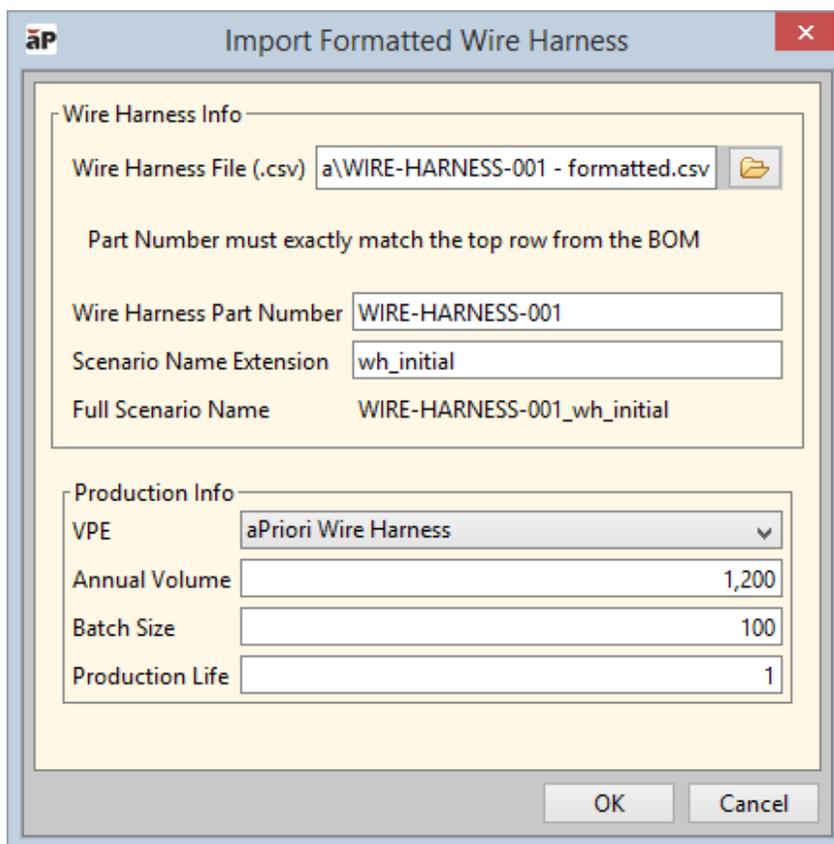
- 2 aPriori prompts you to specify whether you want to import a Wire Harness, import a formatted Wire Harness, or modify the settings of the currently open Wire Harness.

If you are costing a harness defined by a single .csv file in aPriori's format then select **Import New Formatted Wire Harness** then click **OK**. (This is the most common situation.)



- 3 This displays the **Import Formatted Wire Harness** dialog, where you specify the wire harness file as well as production information such as VPE name and volume (similar to the Cost Guide for other process groups).

Note: It is critical that the Wire Harness Part Number provided in the Import Formatted Wire Harness dialog matches the part number for the wire harness in the .csv file. If they do not match, costing will fail.



To validate your initial costing

aPiori recommends that you validate your results, especially when first getting started with wire harness costing. This means manually checking the number of components in the assembly against the number of components listed on your wire harness drawing and/or output tables.

- 1 Go to the **Assembly Details** tab and scroll horizontally to the **Custom Outputs** columns. (We recommend closing the **Cost Guide** and the **Messages** panel to provide the maximum space to the **Assembly Details** tab. Then use the table icons to expand the entries and size all the columns to their contents.)

Cost Object					Custom Outputs	
Status	Level	Name	Scenario	Quantity	Output Name	Output Value
●	0	PN141107_001A	pn141107_...	1		
●	1	Assembly Processes		2		
●	-	Assembly				
●	-	Wire Termination			Copper Surcharge (USD)	0.00
●	-	Wire Marking				
					Distance Between Marks (mm)	50.00
					Length of Wires to Mark (mm)	120,777.00
					Marking Rate (marks per hour) (hr ⁻¹)	6,000
●	-	Manual Crimp				
					Number of Manual Crimped Contacts	-
					Number of Manual Crimped Ring/Fork/Blade Terminals	14
					Number of Manual Crimped Wire Ferrules	-
●	-	Machine Crimp				
					Number of Machine Crimped Contacts	102
					Number of Machine Crimped Ring/Fork/Blade Terminals	-
					Number of Machine Crimped Wire Ferrules	-
●	-	Heat Shrink				
					Number of Heat Shrunken Connections	30
●	-	Connector Assembly				
					Number of Backshells	1
					Number of Coax Connectors	-
					Number of Contacts	102
					Number of Dust Caps	1
					Number of Plugs	54
					Number of Ribbon Cable Connectors	-

- 2 Under the **Assembly Process**, examine the **Output Value** column and compare the quantities there to the quantities in your wire harness output tables and/or schematics. This step ensures that the Transformation Utility correctly processed all of the components in your harness design. So, for example, if your wire harness design tables call for 114 machine crimped contacts and the aPiori Assembly Details table shows only 102, you need to track down why 12 are missing. Or if the wire harness has some number of manual crimped wire ferrules and the Assembly Details table shows none, you need to find out why a process has been skipped over.

The long term, correct solution is to track down the errors, run the Transformation Utility again, re-load the BOM, and re-cost. However, if you are just learning how to cost wire harnesses, or if you are under a deadline, you can temporarily override the **Output Values** to correct quantities.

Common errors that can result in discrepancies include:

- something is not typed correctly
 - the component is missing from the Component Library (or it exists in the library but does not have a price, or is missing a type designation)
- 3** Another adjustment that you can make would be to add additional operations that might not be called out explicitly on the original BOM. For example, labeling operations might not be in the BOM and therefore would not automatically show up in the **Assembly Details** tab. To manually add such an operation, bring up the **Routing Selection** editor by selecting the assembly and clicking **Edit > Routing Selection** in the **Manufacturing Process** panel). Add the missing process and adjust the quantity in the **Process Setting Options**. (For more information, see the "Selecting a process routing" section of the *aPriori User Guide*).

Once you have successfully imported your wire harness, validated it, and obtained a reasonable initial costing, you can proceed to use it in aPriori in much the same way you would work with a geometry-based assembly and its component parts.

Cost Algorithms and Calculations

Wire harness costing is spread across two process groups: Assembly and User Guided. Most costing factors are found in the Assembly Process Group. Only the purchase cost of the wire harness components, and the cost of cutting and stripping wires and dressing components are found in the User Guided Process Group. Many of the following processes allow for user overrides. See *User Inputs* on page 1462 for more information.

aPiori values and calculations have been compiled from various industrial sources and from time studies in industrial applications, to provide reasonable defaults.

Material Cost Calculations

Costs are based on purchased components: The unit cost is extracted from the Component Library, which is configured by an aPiori VPE administrator. Since these values are calculated per subcomponent, the quantity of identical part numbers is not an issue -- it is automatically accounted for. Components purchased by length instead of quantity are calculated as such.

Cutting and Stripping (User Guided)

aPiori uses the values and calculations below to determine costs associated with cutting and stripping wire and dressing components.

Note: All descriptions after this one (Cutting and Stripping) belong to the Assembly Process Group.

Cutting

Cutting is a function of the Wire (W) or Dressing (D) types.

The cutting time for each type is stored in the aPiori machine tables, and ranges from approximately 10 seconds for coax cable to 60 seconds for ribbon cable when performed manually. Times range from approximately 1.7 seconds for coax cable to 10 seconds for ribbon cable when using an automatic machine.

For automatic machines, there is an additional setup time added for unique part numbers.

Stripping

Stripping is a function of the Wire (W) type.

The stripping time for each type is stored in the aPiori machine tables, and ranges from approximately 12 seconds for a Single Conductor Stranded Insulated Wire to 330 seconds for Triax Cable, using a manual stripper tool.

Corresponding times range from 2 seconds to 55 seconds when using an automatic stripping machine.

For automatic machines, there is an additional setup time added for unique part numbers.

Wire Termination

Preparation can include manual, automatic, or semi-automatic steps such as:

- wire marking
- crimp (manual or machine)
- solder
- tin
- heat shrink

Wire Marking

Wire Marking is a function of the Wire (W) type, and wire length, number of wires, and machine marking speed. The batch setup time is multiplied by the number of individual wires. Setup time of 2 minutes is estimated by manufacturers in the industry.

Process time = (Number of Marks) / (Marking Rate)

Number of Marks = (Length To Mark) / (Distance Between Marks)

Default values for Marking Rate and Distance Between Marks is derived from the aPriori machine tables where the actual variables are lengthBetweenWraps and defaultMarkingRate.

Crimping

Crimping is a function of the Terminations (T) type and the subtype quantity. Subtypes include Contacts, Ring/Fork/Blade Terminals, Shield Terminators, and Wire Ferrules.

Process Time = EITHER
(Contact Task Time) * (Number of Manual Crimped Contacts) +
(Ring, Fork, or Blade Task Time) * (Number of Manual Crimped Terminals) +
(Wire Ferrule Task Time) * (Number of Manual Wire Ferrules)

OR

(Contact Task Time) * (Number of Machine Crimped Contacts) +
(Ring, Fork, or Blade Task Time) * (Number of Machine Crimped Terminals) +
(Wire Ferrule Task Time) * (Number of Machine Wire Ferrules)

Because of the large variety of crimp terminals, cycle times can vary widely. Likewise, the speed of various semi-automatic crimping machines can be different, meaning that production rates will vary from machine to machine. Machine crimping is much faster than manual crimping, but has a set-up time element.

Task time defaults are all derived from aPriori machine tables.

Quantities are all extracted from the input .csv files or supplied via user override.

Soldering

Soldering is a function of the Terminations (T) type and subtype quantity. Subtypes include Contact, Ring/Fork/Blade Terminal, Shield Terminators.

Process Time =
(Contact Task Time) * (Number of Contacts) +

(Terminal Task Time) * (Number of Ring or Fork Terminals) + (Terminator Task Time) * (Number of ShieldTerminators)

Task time defaults are all derived from aPiori machine tables.

Quantities are all supplied by the input files or user override.

Tinning

Tinning is a function of the Terminations (T) type and subtype quantity. Subtypes include Tinned Wire (T3).

Process Time = ((Tinned Wire Task Time) * (Number of Tinned Wires))

Tinned Wire Task Time is derived from aPiori machine tables.

Number of Tinned Wires is supplied by the input files or user override.

Heat Shrinking

Heat Shrinking is a function of the Terminations (T) type and subtype quantity

Process Time = (Per Piece Task Time) * (Number of Heat Shrink Connections)

Per Piece Task Time is derived from aPiori machine tables.

The Number of Heat Shrink Connections is supplied by the input files or user override. If this value is not specified, a default is calculated from (Number of Ring, Fork, or Blade Terminals) + (Number of Ultrasonic Splices).

Connector Assembly

Connector Assembly is a function of the Connectors (C) type and subtype quantity.

The cycle time for assembling a loaded or unloaded connector is determined by the number of accessories required. A cycle time is attributed to each accessory, such as:

- Contact insertion
- Wire Seal insertion
- Plug insertion
- Wedge Lock insertion
- Backshell attachment
- Strain Relief attachment
- Shrink Boot attachment

Ribbon cable connectors, coax cable connectors, and triax cable connectors do not have as many variants as above, and therefore each has its own, single standard cycle time.

Process Time =

(Unloaded or Loaded Connector Time) + (Ribbon Cable Connector Time) + (Coax Cable Connector Time) + (Triax Cable Connector Time)

Unloaded or Loaded Connector Time =

(Stuff Contact Time) * (Number of Contacts) + (Stuff Wire Seal Time) * (Number of Wire Seals) + (Stuff Plug Time) * (Number of Plugs) + (Stuff Wedglock Time) * (Number of WedgeLocks) +

(Attach Backshell Time) * (Number of Backshells) +
(Attach Strain Relief Time) * (Number of Strain Reliefs) +
(Attach Shrink Boot Time) * (Number of Shrink Boots) +
(Solder Wire Time) * (Number of SolderedWires) +
(Potting Application Time) * (Number of PottingApplications) +
(Attach Dust Caps Time)* (Number of DustCaps)

Ribbon Cable Connector Time = Ribbon Cable Connector Time * Number of Ribbon Cable Connectors

Coax Cable Connector Time = Coax Connector Time* Number of Coax Connectors

Triax Cable Connector Time = Triax Connector Time * Number of Triax Connectors

Time values are all plant variables -- see the table in *Process Defaults and Thresholds*.

Quantities are all provided from the input files or user override.

Splice

Ultrasonic Weld

Ultrasonic Weld is a function of the Splices (P) type and subtype quantity. Subtype is Ultrasonic welds (P3).

Process Time = (Per Piece Task Time) * (Number of Ultrasonic Welds)

Per Piece Task Time is derived from the aPriori machine tables. Default is 180 seconds.

Number of Ultrasonic Welds is provided by the input files or user override.

Butt Splice

Butt Splice is a function of the Splices (P) subtype and subtype quantity (requires connector component called out in BOM). Subtype is Butt Splice (P2).

Process Time = (Per Piece Task Time) * (Number of Butt Splices)

Per Piece Task Time is derived from the aPriori machine tables. Default is 36 seconds.

Number of Butt Splices is provided by the input files or user override.

Insulation Displacement Splice

Insulation Displacement Splice is a function of the Splices (P) subtype and subtype quantity. Subtype is Insulation Displacement Splice (P3).

Process Time = (Per Piece Task Time) * (Number of Insulation Displacement Splices)

Per Piece Task Time is derived from the aPriori machine tables. Default is 36 seconds.

Number of Insulation Displacement Splices is derived from input files or user override.

Harness Layout

Formboard Setup/Test

Process Time = ((Number of Connectors) / (Formboard Testing Rate))

Wire Layout

Process Time = (Wire Layout Time) * (Harness Assembly Factor) * (Unmarked Wire Factor)

Wire Layout Time =

**((Easy Wire Base Layout Time) + ((Easy Wire Handling Time) * ((Length of Easy Wires)/MM_PER_IN))) +
 ((Difficult Wire Base Layout Time) + ((Difficult Wire Handling Time) * ((Length of Difficult Wires)/MM_PER_IN)))+
 ((Ribbon Cable Base Layout Time) + ((Ribbon Cable Handling Time) * ((Length of Ribbon Cable) / MM_PER_IN)))**

Harness Assembly Factor = (Manual Harness Assembly Factor)

Unmarked Wire Factor = (Unmarked Wire Factor)

All times and factors are derived from aPiori plant variables (see the table at *Process Defaults and Thresholds*).

All lengths are derived from input files or user override.

Branch Layout

Process Time = (Branch Layout Time) * (Harness Assembly Factor)

Branch Layout Time = EITHER

**((Branch Layout Cable Tie Time) * (Number of Spot Wraps) OR
 ((Spot Tape Time) * (Number of Spot Wraps)) + ((Breakout Tape Time) * (Number of Bundles))**

Number of Spot Wraps = Roundup((Length of Bundles) / (Length Between Wraps)) + (2 * (Number of Bundles))

All times and factors are derived from aPiori plant variables (see the table at *Process Defaults and Thresholds*).

All lengths and numbers are derived from input files or user override.

Twist

Process Time = (Total Twist Length) / (Twist Rate)

Branch Covering

Branch covering is a function of Bundle (B) type and quantity and subtype. Subtypes can include: Single Braided, Double Braided, Expando Braided, Split Loom, Spiral Wrap, Seal Tape, Braid, Plain Flexible Conduit, Liquid Tight Conduit, EMI Braiding

Overrides: Qty of each subtype

Branch Covering can be used for abrasion protection or simply to contain a group of wires or cables. Coverings can extend across an entire harness, or be applied just to certain areas.

Braid

Braiding is a function of the Dressing D3 (Braid) sub-type, and the bundle length/diameter, unit cost of braiding material, braid angle, and weight of braiding material

Process Time = (Total Braid Length) * (Braiding Rate)

Total braid length is derived from the Dressing Length UDA (or user override)

Required Yarn Length in millimeters = Number of Carriers * Max Bundle Diameter * PI / cos(Braid Angle)

Braiding rate, Maximum Bundle Diameter, and Number of Carriers is derived from the machine tables.

Default braiding Angle is 45 degrees and is user overridable via Process Setup Options.

Label

Labelling is a function of the Label (L) type, for the specific subtypes listed below.

Heat Shrink Label

Function of the Heatshrink (L1) subtype and quantity.

Process Time = (Per Piece Task Time) * (Quantity of Heat Shrink Labels)

Per Piece Task Time: Derived from the aPriori machine tables (default = .95 seconds).

Quantity is by default is zero since this is not typically specified in the wire harness output table. Provide a quantity value through Process Set-up Options (see *User Inputs* below).

Wrap-Around Label

Function of the Wrap-around (L2) subtype and quantity.

Process Time = (Per Piece Task Time) * (Quantity of Wrap-Around Labels)

Per Piece Task Time: Derived from the aPriori machine tables (default = 10 seconds).

Quantity by default is zero since this is not typically specified in the wire harness output table. Provide a quantity value through Process Set-up Options (see *User Inputs* below).

Test

Pull Test

Process Time = (Quantity of Terminations) * (Pull Test Task Time) * (Percent of Terminations to Pull Test)

Quantity of Terminations is provided by the input files or user override.

Pull Test Task Time: Derived from the aPriori machine tables (default = 60 seconds).

Percent of Terminations to Pull Test = (Quantity of Unique Terminations) / (Quantity of Terminations).

If the Quantity of Terminations is zero, then the Percent of Terminations to Pull Test is zero.

Continuity Test**Process Time = (Per Piece Task Time) * (Quantity of Connectors)**

Per Piece Task Time: Derived from the aPriori machine tables (default = .5 seconds).

Quantity of Connectors is provided by the input files or user override.

Hipot Test**Process Time = (Per Piece Task Time) * (Quantity of Connectors)**

Per Piece Task Time: Derived from the aPriori machine tables (default = 1 second).

Quantity of Connectors is provided by the input files or user override.

User Inputs

You can control the values listed below by modifying **Process Setup Options**, or plant variables.

To access **Process Setup Options** for a given process, right click the process in the Manufacturing Process pane, and select **Process Setup Options** from the context menu.

See *Process Defaults and Thresholds* for more information on plant variables.

The Wire Harness Assembly process group provides the following process setup options:

- Wire Marking

All of the following can be overridden with user values. Defaults are set as described below.

- Distance Between Marks -- Default is determined by the plant variable `defaultDistanceBetweenMarks` (see the table at *Process Defaults and Thresholds*).
- Marking Rate -- Default is determined by the plant variable `defaultMarkingRate` (see the table at *Process Defaults and Thresholds*).
- Length to Mark -- Default is calculated by summing together all wire lengths from input files or user override.

- Manual Crimp

In each of the following, the default value is the number of the type of crimps provided by the input files or user override:

- Number of Manual Crimped Contacts
- Number of Manual Crimped Terminals
- Number of Manual Crimped Wire Ferrules

- Machine Crimp

In each of the following, the default value is the number of the type of crimps provided by the input files or user override utility:

- Number of Machine Crimped Contacts
- Number of Machine Crimped Terminals
- Number of Machine Crimped Wire Ferrules

- Solder

In each of the following, the default value is the number of the type of solder connections provided by the input files or user override:

- Number of Soldered Contacts
- Number of Soldered Ring/Fork/Blade Terminals
- Number of Soldered Shield Terminators

- Tin

In the following, the default value is the number of tinned wires provided by the input files or user override.

- Count Tinned Wires

- Heat Shrink

In the following, the default value is the number of connections provided by the input files or user override:

- Count Heat Shrunken Connections
- Connector Assembly

With the exception of Potting Applications, the default value for each of the following types is provided by the input files or user override:

- Number of Backshells
 - Number of Contacts
 - Number of Plugs
 - Number of Shrink Boots
 - Number of Soldered Wires
 - Number of Strain Reliefs
 - Number of Wedgelocks
 - Number of Wire Seals
 - Number of Dust Caps
 - Number of Ribbon Cable Connectors
 - Number of Coax Connectors
 - Number of Triax Connectors
 - Number of Potting Applications -- Default = 0. Any potting applications must be input as a PSO.
- Splices: Ultrasonic, Butt, Insulation Displacement

In the following, the default value is provided by the input files or user override:

- Number of Ultrasonic Splices
- Number of Butt Splices
- Number of Insulation Displacement Splices

- Branch Layout

In the following, the default value is determined by the setting of the plant variable `lengthBetweenWraps`, which applies to tape or ties (see the table at *Process Defaults and Thresholds*). This value can be overridden by a user value.

- Length Between Ties

- Twist

Both of the following settings can be overridden with user values. The default values are determined as described below:

- Twist Length -- The default twist length is derived from the User Defined Attribute of the same name.
- Twist Rate -- The default twist rate is derived from the machine tables.

- Braid

All of the following can be overridden with user values. Defaults are set as described below.

- Length of Braid -- Default is derived from the Dressing Length UDA
- Braid Angle -- Default is derived from the plant variable `defaultBraidAngle` (see the table at *Process Defaults and Thresholds*).

- Unit Cost of Braiding Material -- Default is derived from the plant variable yarnUnitCost (see the table at *Process Defaults and Thresholds*).
- Unit Weight of Braiding Material -- Default is derived from the plant variable yarnUnitWeight (see the table at *Process Defaults and Thresholds*).
- Labels: Heat Shrink, Wrap-Around

The number of each of these labels can be overridden with user values. Default values are typically zero because labels are not usually specified in wire harness output tables.

 - Number of Heat Shrink Labels
 - Number of Wrap-Around Label
- Pull Test

The percentage of terminations to pull test can be overridden with a user value. The default is computed as shown.

 - Percentage of Terminations Pull-Tested -- The default value is determined by the number of unique terminations divided by the number of all terminations. If the number of all terminations is zero, then the default is zero.
- Tests: Continuity Test, Hipot Test

The number of connectors to test for each of these test types. The default is the number of connectors provided by the input files or user override.

 - Number of Connectors to Test

Process Defaults and Thresholds

Process group site variables control several aspects of wire harness costing. Any wire harness entry can be adjusted as necessary for your local installation. Follow these steps to access plant variables for a given VPE and process:

- 1 Select **Tools > VPE Toolset**, and then click the **VPE Manager** button in the VPE Toolset window.
- 2 Double click the **Wire Harness VPE** in the **Select VPE** window.
- 3 In the **VPE Manager**, click + to expand the **Assembly** and **User Guided** process groups.
- 4 Under these groups, click **Variables**.
- 5 There is one variable of particular interest in the **User Guided** Process Group: **automaticProductionThreshold**. The setting of this variable determines whether aPiori will assign cutting and stripping operations to manual or to semi-automatic or automatic machines. The default threshold is an annual volume of 50.
- 6 Many wire harness variables are available in the Assembly Process Group, and are well documented in the comments columns. The following table lists the wire harness settings as of this writing. Use the procedure above to list the most up-to-date variables. The values in this table have been compiled from various industrial sources or from time studies in industrial applications, to provide reasonable defaults. You can adjust them if necessary to reflect your specific installation.

<i>Variable Name</i>	<i>String Value</i>	<i>Unit Type Name</i>	<i>Notes</i>
applyHeatShrinkConstantTime	7.9	Time	Constant time (in seconds) allotted for installing and shrinking heat shrink tubing as branch covering (regardless of bundle length).
applyHeatShrinkPerInTime	8.616	Time	Time (in seconds) allotted for installing and shrinking heat shrink tubing as branch covering (per inch).
applySealTapeConstantTime	7.6	Time	Constant time (in seconds) allotted for applying seal tape as a branch covering (regardless of bundle length).
applySealTapePerInTime	1.1	Time	Time (in seconds) allotted for applying seal

			tape as branch covering (per inch).
attachBackshellTime	70	Time	Time (in seconds) allotted to attach a backshell to a connector.
attachDustCapsTime	60	Time	Time (in seconds) to attach a dust cap to a loaded or unloaded connector.
attachShrinkBootTime	140	Time	Time (in seconds) allotted to attach a shrink boot to a connector.
attachStrainReliefTime	90	Time	Time (in seconds) allotted to attach strain relief to a connector.
automaticProductionThreshold	50		Annual production volume above which semi-automatic or automatic machines are used when available. Below this threshold, only manual tools are used.
branchLayoutCableTieTime	5	Time	Time (in seconds) allotted to apply each cable tie during branch layout.
breakoutTapeTime	8	Time	Time (in seconds) allotted to seal tape each bundle break out.
coaxConnectorTime	360	Time	Time (in seconds) allotted to connect each coax connector.
defaultBraidAngle	45	Angle	Default braid angle for harness braiding machine.
defaultDistanceBetweenMarks	50	Length	Maximum linear increment along the total length of the wire for placing circuit identifications during wire marking.

defaultMarkingRate	6000	hr ⁻¹	Default number of marks per hour achieved by the Wire Marking process.
diffWireBaseLayoutTime	6.2	Time	Base time (in seconds) allotted for the layout of difficult to lay in wires (stiff wires, multi conductor cables, etc.).
diffWireHandlingTime	1.2	Time	Additional handling time (in seconds) allotted per foot for the layout of easy to lay in wires (stiff wires, multi conductor cables, etc.).
easyWireBaseLayoutTime	4.2	Time	Base time (in seconds) allotted for the layout of easy to lay in wires (flexible single wire).
easyWireHandlingTime	0.8	Time	Additional handling time (in seconds) allotted per foot for the layout of easy to lay in wires (flexible single wire).
formboardTestingRate	240	hr ⁻¹	Number of connectors that can be tested per hour using formboard testing.
installSleeveConstantTime	7.9	Time	Constant time (in seconds) allotted for installing a tube or sleeve as branch covering (regardless of bundle length).
installSleevePerInTime	2.217	Time	Time (in seconds) allotted for installing a tube or sleeve as branch covering (per inch).
installSplitTubeConstantTime	8	Time	Constant time (in seconds) allotted for installing split tubing as branch covering (regardless of bundle length).

installSplitTubePerInTime	.5167	Time	Time (in seconds) allotted for installing split tubing as branch covering (per inch).
lengthBetweenWraps	250	Length	Length between sections of a bundle that are wrapped with tape or a cable tie.
manualArcTimeStandard	1.32		Unused in Wire Harness cost model.
manualHarnessAssemblyFactor	1.3		Factor to account for additional assembly time when harness is assembled by hand instead of using a formboard.
pottingApplicationTime	480	Time	Standard time (in seconds) to apply potting to a connector.
ribbonCableBaseLayoutTime	6.2	Time	Base time (in seconds) allotted for the layout of easy to lay in ribbon cables.
ribbonCableConnectorTime	120	Time	Time (in seconds) allotted to connect each ribbon cable connector.
ribbonCableHandlingTime	1.8	Time	Additional handling time (in seconds) allotted per foot for the layout of ribbon cables.
solderWireTime	120	Time	Time (in seconds) required to solder a single wire into a connector.
spotTapeTime	3	Time	Time (in seconds) allotted to apply tape for pre-bundling during branch layout.
stuffContactTime	25	Time	Time (in seconds) allotted to insert each contact into a connector.
stuffPlugTime	80	Time	Time (in seconds) allotted to insert each plug into a connector.

stuffWedgeloackTime	14.4	Time	Time (in seconds) allotted to insert each wedgeloack into a connector.
stuffWireSealTime	6	Time	Time (in seconds) allotted to insert each wire seal into a connector.
triaxConnectorTime	360	Time	Time (in seconds) allotted to connect each triax connector.
unmarkedWireFactor	1.2		Factor to account for additional difficulty in harness assembly when wire marking is not used for circuit identification.
useFormboard	true		Set to true if a formboard is used for assembly. Set to false if harness assembly is done by hand.
yarnUnitWeight	2015	m/Mass	Length per mass of braiding material.
yarnUnitCost	7.63	Currency/Mass	Unit cost of braiding material.

Process Limitations:

The aPriori Wire Harness process group does not support the following processes:

Category	Processes Not Supported
Encapsulation	Over-molding
<i>Testing</i>	Shorts Dielectric Insulation Resistance (IR) Voltage Standing Wave Ratio Insertion Loss Reflection Coefficient Crimp Height Crimp Force Monitoring
Wire Prep	Chemical wire stripping Thermal wire stripping
Splices	Mesh splices Wrapped soldered splices Hook soldered splices Lag splices Wire in-line junction devices Clip splices
Harness Layout	Lacing

Note that aPriori does not currently support mechanical components in the wire harness assembly, and does not cost installation of the interconnections or of the cable harness into the chassis or product.



31 PCBA Process Group

This section describes aPriori's capabilities for costing printed circuit board assemblies.

This chapter includes the following topics:

- Cost Model Overview
 - Modifying and Importing Your PCBA BOM
 - Cost Algorithms and Calculations
 - How to Cost a PCBA
 - PCBA Processes – User Guided
 - PCBA Processes -- Assembly
 - Process Defaults and Thresholds
-

PCBA Cost Model Overview

The PCBA cost model provides the ability to automatically cost rigid printed circuit board assemblies (PCBAs). The major cost drivers for PCBAs are:

- The cost of the individual components comprising the PCBA
- The cost of assembling, testing, and performing any other processes needed to manufacture the PCBA from those components

The current release of this functionality does not cover rigid-flex or flexible circuit board assemblies, nor does it cover the design and manufacture of the boards themselves, which are considered components with a user-provided cost.

The primary use cases for aPriori PCBA costing include providing:

- Early estimates for new product introduction (NPI)
- Quote evaluation
- Outlier analysis

If you are an engineer designing a PCBA, you can create or modify your design and then generate and cost a BOM to check your costs immediately, allowing you to make design decisions now rather than weeks later when receiving supplier quotes.

If you work in purchasing, you can analyze your PCBA costs at a component level, and start to negotiate from a more knowledgeable position with your suppliers.

The separately-licensed PCBA cost model is somewhat different than most other aPriori process groups (other than Wire Harness): it is implemented as a VPE with two process groups:

- a “user guided” process group containing an aPriori-configured Component Library that provides cost information for all PCBA-related parts used by your company
- a PCBA assembly process group defining all of the processes needed to create a PCBA from its constituent components

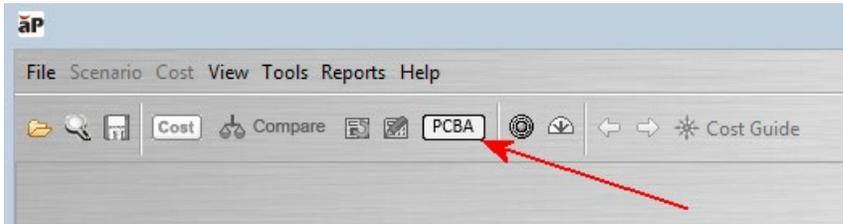
You do not really need to be concerned with this architectural detail, since aPriori configures the PCBA cost model specifically for your company, and provides an easy-to-use interface to walk you through the costing process. But if you are an experienced aPriori user who wants to understand how the PCBA cost model works, here is some more information.

The reason for this approach is that even though PCBAs are considered a type of assembly, geometric cost drivers (GCDs) are not available the same way they would be for CAD model-based components. Instead, aPriori extracts cost driver information from the BOM describing the elements making up your PCBA. This information is augmented with user-guided data such as the purchase price of the board itself or the selection of optional routings, and with component library information. Most components will be off-the-shelf parts, but we know that many companies specify internal part numbers rather than manufacturer or distributor part numbers. To associate information from the tables to the purchased component information, aPriori Professional Services first maps your internal part numbers to manufacturer or distributor part numbers in a Component Library in the VPE.

This chapter covers day-to-day costing use operations and assumes that aPiori Professional Services has worked with your administrators to set up and configure this cost model, including the Component Library. See the aPiori *System Administration Guide* and *VPE Administration Guide* for more information about configuration and maintenance of the PCBA environment.

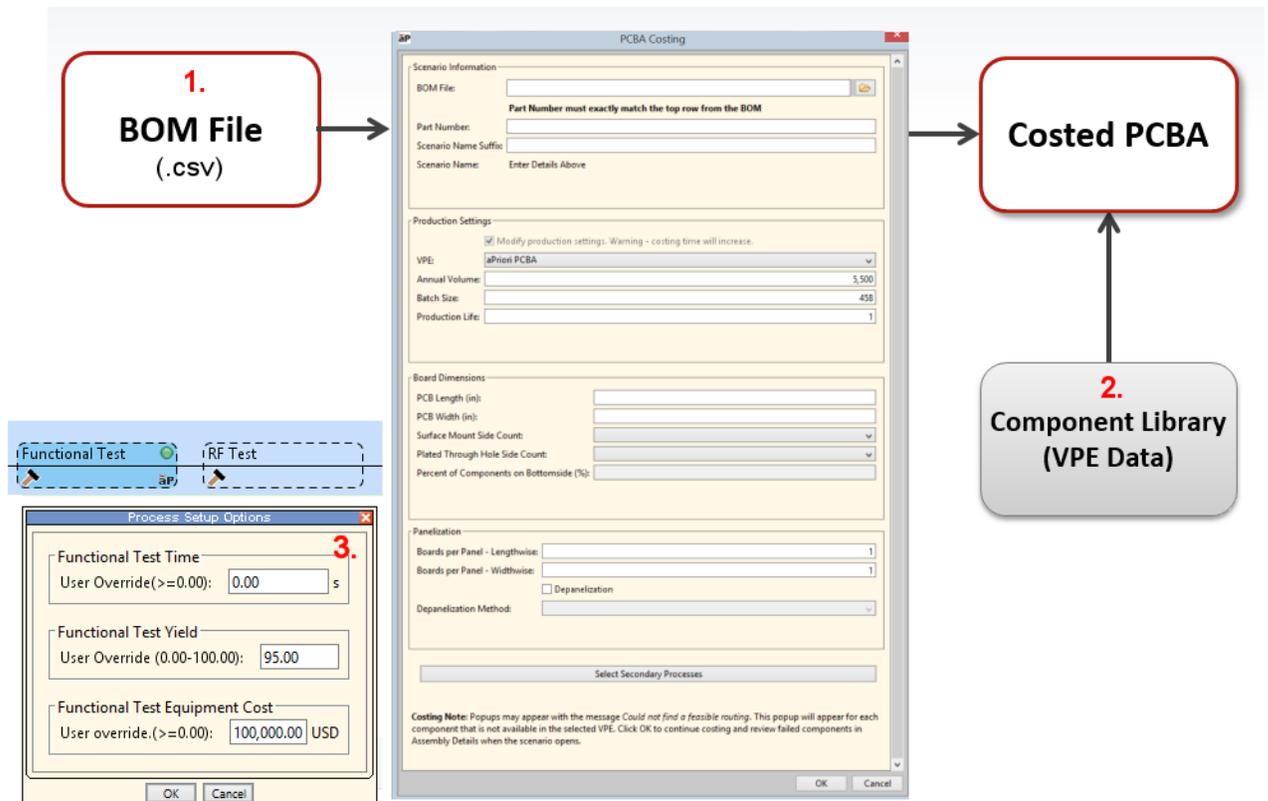
PCB Costing Workflow

Instead of using the standard **Cost Guide** that you would typically use for costing mechanical part, you start the costing process with a **PCBA** button that appears when aPriori has been configured for PCBA costing.

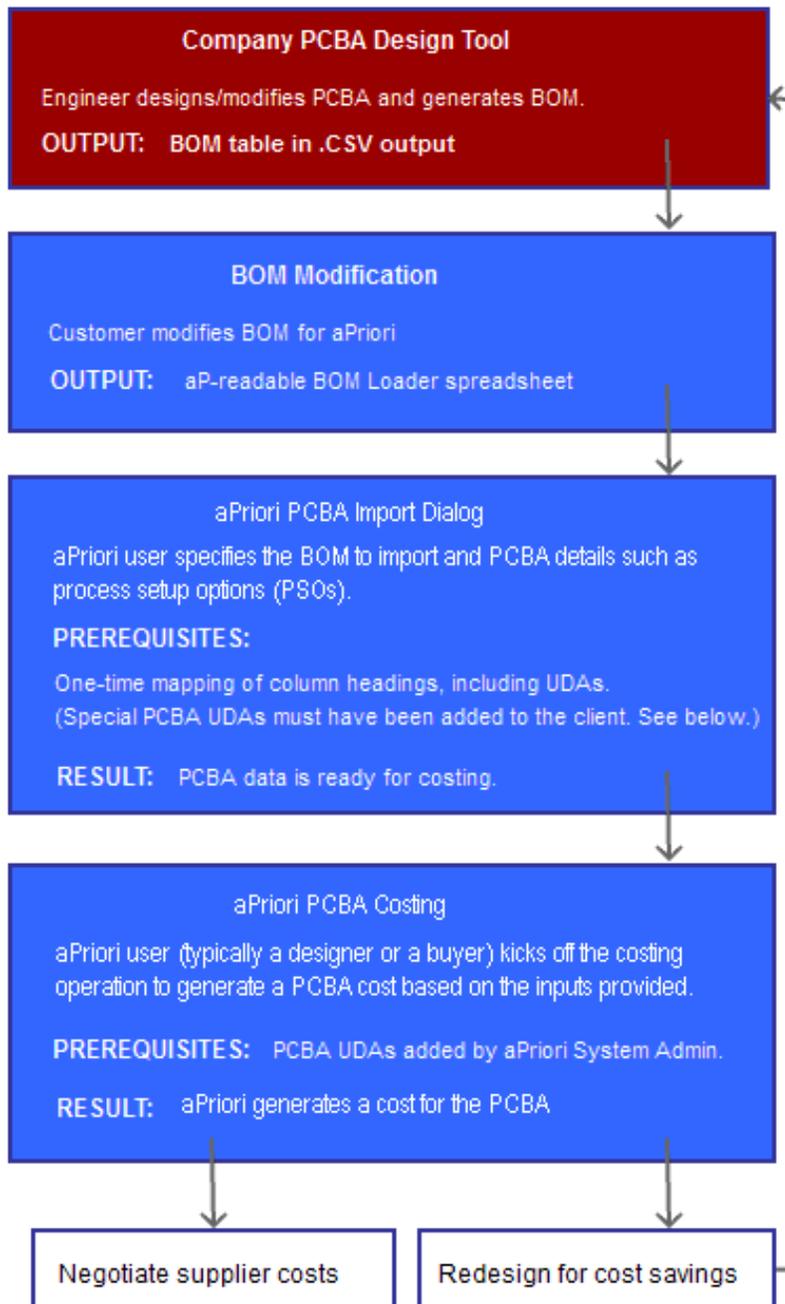


To cost a PCBA, aPriori requires the following inputs:

- 1 A Bill of Materials (BOM) spreadsheet from your PCBA design tool in a standardized, .csv format.
- 2 Standard prices for purchased components, typically in the form of a Component Library that is initially configured by aPriori Professional Services, and thereafter maintained by an aPriori administrator at your company, mapping your Customer Part Numbers to Manufacturer Part Numbers.
- 3 User inputs in the form of values provided via the **PCBA Costing** dialog box that appears when you click the **PCBA** button (or later as individual PSO settings).



The following diagram provides a more high-level view of the PCBA costing workflow:



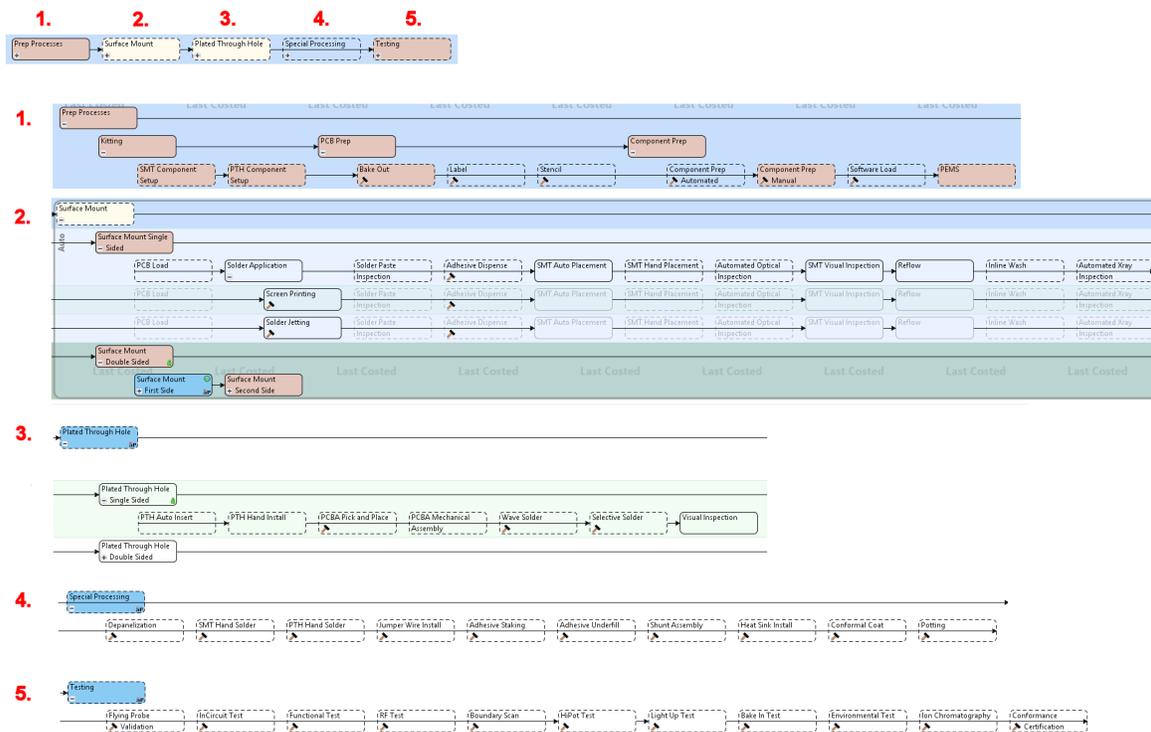
aPriori does not make any assumptions about which specific PCBA design tool is being used. The one assumption that we do make is that the tool can output a BOM spreadsheet file to a .csv table format that you can modify. aPriori imports this spreadsheet with the aPriori BOM loader.

General Process

PCBAs are assemblies that consist of mostly purchased components with a variety of assembly and testing processes that may be required to complete the end product.

Routings

The Assembly Process Group routings for PCBA are summarized in the following illustration. The text is small, so the illustration is followed by a listing of the processes shown. (You can always display the full routing diagram in the aPriori client by clicking **Edit > Routing Selection** in the **Manufacturing Process** pane, and ensuring that **View > Show Uncosted Nodes within Visible Routings** is selected in the **Routing Selection** window.)



- 1 Prep Processes** -- Surface Mount Technology (SMT) Component Setup, Plated Through Hole (PTH) Component Setup, Bake Out, Label, Stencil, Automated Component Prep Automated, Manual Component Prep, Component Software Load, PEMS/MSDS
- 2 Surface Mount** -- (single and double sided) - PCB Load, PCB Flip, Screen Printing, Solder Jetting, Solder Paste Inspection, Adhesive Dispense, SMT Auto Placement, SMT Hand Placement, Automated Optical Inspection, SMT Visual Inspection, Reflow, Inline Wash, Automated Xray Inspection
- 3 Plated Through Hole** -- PTH Auto Insert, PTH Hand Install, Wave Solder, Selective Solder, Visual Inspection
- 4 Special Processing** --Depanelization, SMT Hand Solder, PTH Hand Solder, Jumper Wire Install, Adhesive Stake, Adhesive Underfill, Shunt Assembly, Heat Sink Install, Batch Wash, Conformal Coat, Potting, Final Assy

- 5 **Testing** -- Flying Probe Validation, InCircuit Test, Software Load, Functional Test, RF Test, Boundary Scan (JTAG), HiPot Test, Light Up Test, Bake In/Burn In Test, Environmental Test, Ion Chromatography, Conformance Certification

Modifying and Importing Your PCBA BOM

The primary input to aPriori for PCBA costing is a Bill of Materials (BOM) file in .csv format. This BOM may come from your PCB design software, PLM system, ERP software, etc., depending on where the PCBA is in its lifecycle and how your company works.

Regardless of its source, you must make some minor adjustments to the BOM data before you can import it into aPriori. The following table shows the required and optional columns that you should consider when adapting your BOM for import to aPriori. Note that the specific column names are not critical since you will be mapping these columns to aPriori columns when you import. For example, "LEVEL", "Level", and "Lvl" are all acceptable candidates for the level column, and will be mapped to the "Level" field in aPriori. However, you should be consistent in your naming convention across different BOMs. See the aPriori *VPE Administration Guide* for information about mapping PCBA BOM column headers to aPriori fields.

Column Heading	Required?	Comments
Level	Y	PCBAs should have only two levels, either 0 and 1, or 1 and 2. The top-level PCBA assembly part number should be level "0" or "1". All other components should be level "1" or "2". All other levels will be ignored.
Part Number	Y	This column contains the name of the part, which may be a reference designator to a drawing, or may be the internal company part number. If the latter, make sure that it matches the entries in the COMPONENT_PART_NUMBER column (see below).
Quantity	Y	The number of instances of the component on this PCBA.
Description	N	Any string that helps identify the component: "Fuse sm 5A", "IC 5V voltage regulator", "Capacitor 33UF 25V 20%", etc.
Manually Costed	Y	Identifies any part which is not automatically costed but which is provided by the user. ONLY the row for the printed circuit board itself - or for components that you do not wish to cost in the PCBA cost model (such as schematics, work instructions, or some other non-costed line item) -- should be set to TRUE. All other rows should be set to FALSE.
Component Pn	Y	This column contains the internal company part number for each component.
Material Cost	Y	Captures the cost of the PCB itself.
Unit Cost ¹	N	The current cost that your company is paying for this component.
Unit Type ¹	N	Typically "Each", but could be "IN", "MM", or "U/M" (unit of measure) depending on the component.
Purchase Date ¹	N	The most recent purchase transaction.

Column Heading	Required?	Comments
Preferred Source ^{1,2}	N	A non-distributor component costing source such as internal data, web pricing, or contract manufacturer.
Preferred Supplier ²	N	The distributor that sells the component.
Preferred Manufacturer ²	N	The company that builds the component.
Pin Count ³	N	Any integer greater than zero.
Mount Type ³	N	Either "Surface Mount" or "Through Hole"
Purchase Volume ¹	N	Specify the purchased volume for each component independent of the annual volume.

1. These fields provide the ability to capture existing purchase data specific to this BOM. These will be used when costing the PCBA if they provide a lower cost than provided by the Component Library.
2. You can specify the supplier, manufacturer, and source that you prefer to use for a component. If the specified supplier, manufacturer, and source exists for that component then this will override values in the component library. If the provided supplier, manufacturer and source do not exist for that component, the component library values are used by default. You can also use Process Setup Options (PSOs) available on the Purchased Component node of each component to select the specific supplier, manufacturer and source to use from the options available in the Component Library.
3. These inputs enable you to cost components that are not available in the Component Library, streamlining the workflow for costing PCBAs with new components. If PIN COUNT, MOUNT TYPE, UNIT COST, and UNIT TYPE are all provided in the BOM file, then the component library lookup will be skipped for that component.

Once you have a PCBA .csv file formatted as described above, you will import it as part of the costing procedure described at [How to Cost a PCBA](#).

To load a 2D image of the PCBA assembly

It is possible that you will want to associate an image of your PCBA with the aPriori assembly, similar to the images that are displayed of components that come into aPriori from CAD files. There are a couple of ways that you can do this. If you have an image file available up front, you can add a column to the BOM Loader import file and specify it at the same time that you create the assembly in aPriori. Or you can add the image at any time later. For more information about adding an image to your component, see the "Specifying 2D Images for virtual components" section of the *aPriori User Guide*.

Cost Algorithms and Calculations

PCBA costing is spread across two process groups: Assembly and User Guided. Most costing factors are found in the Assembly Process Group. Only the purchase cost of the PCBA components are found in the User Guided Process Group. Many of the assembly processes allow for user overrides.

aPriori values and calculations have been compiled from various industrial sources and from time studies in industrial applications, to provide reasonable defaults.

Material costs are based on purchased components: The unit cost is extracted from the Component Library, which is maintained by an aPriori VPE administrator. Since these values are calculated per subcomponent, the quantity of identical part numbers is not an issue -- it is automatically accounted for.

Descriptions of the major cost drivers for each assembly process are provided in [PCBA Processes -- Assembly](#).

How to Cost a PCBA

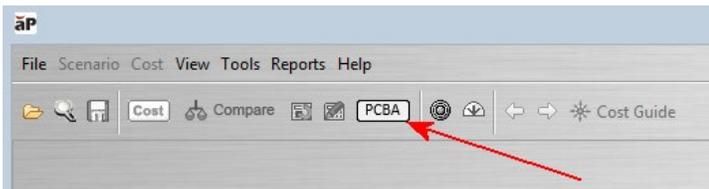
PCBA costing requires the following:

- 1 A version of aPriori that supports PCBA.
- 2 A version of the PCBA Assembly VPE that has been customized for your company, including a Component Library that reflects your Bills of Materials.
- 3 A version of the “project-management-plugin” that supports PCBA.
- 4 User Defined Attributes (UDAs) that support PCBA.
- 5 Mappings in the BOM Loader that assigns BOM column headings to fields in aPriori.

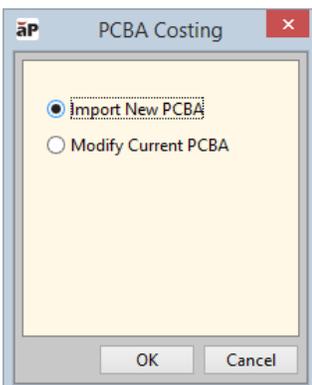
These prerequisites should have been addressed by aPriori Professional Services working in concert with your company’s aPriori administrator(s).

To import and cost a new PCBA assembly

- 1 In the aPriori client, click the **PCBA** button.



- 2 IF you already have a PCBA open, aPriori prompts you to specify whether you want to import a new PCBA for the first time, or modify the settings of the open PCBA. Select **Import New PCBA** then click **OK**. (If no existing PCBA is open, aPriori assumes that you are importing a new PCBA and takes you to the next step.)



- 3** This displays the **PCBA Costing** dialog, where you input important values that describe attributes of the PCBA which are not defined in the BOM. The first page of this dialog allows you to specify “Global Inputs” such as board dimensions which may be needed by several different processes.

aP PCBA Costing

Scenario Information

BOM File: 00000_PCBA_WH_FILES\Demo\OneDrive_1_1-15-2018\PCBA Demo Data\PCBA-001.csv

Part Number must exactly match the top row from the BOM

Part Number: PCBA-001

Scenario Name Suffix: pcb_init

Scenario Name: PCBA-001_pcb_init

Production Settings

Modify production settings. Warning - costing time will increase.

VPE: aPriori PCBA

Annual Volume: 5,500

Batch Size: 458

Production Life: 1

Board Dimensions

PCB Length (in):

PCB Width (in):

Surface Mount Side Count: Surface Mount Single Sided

Plated Through Hole Side Count:

Percent of Components on Bottomside (%):

Panelization

Boards per Panel - Lengthwise: 1

Boards per Panel - Widthwise: 1

Depanelization

Depanelization Method:

Select Secondary Processes

Costing Note: Popups may appear with the message *Could not find a feasible routing*. This popup will appear for each component that is not available in the selected VPE. Click OK to continue costing and review failed components in Assembly Details when the scenario opens.

OK Cancel

Here is a summary of the values that you should provide in this dialog:

Scenario Information – This is where you specify the BOM to import. (It's a good practice to incorporate the part number in the name of the file.)

BOM File –Use the navigation button to specify the full path name of the BOM .csv.

Part Number – **IMPORTANT:** The value you enter here **MUST** be exactly the same as part number as entered in Line #1 of the .csv file.

Scenario Name Suffix – Specify a string that will indicate the level, status, or some other aspect of this costing, such as “initial”, “test”, “asia”, etc. (Full scenario name is reflected in the read-only “Scenario Name” field on the next line.)

Production Settings – With the exception of the checkbox, these settings are the same settings that you find on the **Cost Guide** (see.”Cost Guide” section of the aPriori User Guide for details).

Modify Production Settings – This checkbox enables you to update production inputs. These inputs are pushed down to all child components. This checkbox is only available when recosting PCBAs, and when checked you can change the VPE, Annual Volume, Batch Size and Production Life settings. **Note:** Enabling this option will cause costing to be slower since all subcomponents will be recosted.

VPE – It is critical that you select a VPE that supports PCBA. In most cases, aPriori will not display any non-PCBA VPE. But if your system for some reason is configured to allow this, be aware that selecting a non-PCBA VPE (such as “aPriori USA”), will cause your costing attempts to fail.

Annual Volume – Number of units you expect to manufacture in one year.

Batch Size – Typically Annual Volume/12

Production Life – Number of years you expect the part to be manufactured

Board Dimensions – Physical aspects of the printed circuit board.

PCB Length (in) – Self-explanatory.

PCB Width (in) – Self-explanatory.

Surface Mount Side Count – Specify **Single-Sided**, **Double-Sided**, or **None**.

Plated Through Hole Side Count -- Specify **Single-Sided**, **Double-Sided**, or **None**.

Percent of Components on Bottomside (%) – Required if you have specified **Double-Sided** above.

Panelization – Use this section to specify if multiple PCBAs are built at the same time, and then separated into individual boards.

Boards Per Panel – Lengthwise -- Self-explanatory.

Boards Per Panel – Widthwise -- Self-explanatory.

Depanelization – This checkbox enables you to force depanelization for a 1 x 1 panel. This enables you to more accurately account for the processing required to manufacture boards that come in a sheet that must be trimmed, such as circular or other non-rectangular boards. This checkbox is only

available when 1 x1 panels are specified. Depanelization is assumed for any settings greater than 1 x 1.

Depanelization Method – Specify **Manual** or **Automated**. (If manual, cost calculations will take into account breaking the panels apart by hand. If Automated, use of a band saw is assumed.

When done filling in these fields, click **Select Secondary Processes**

- 4 Use the **Optional Processes** dialog to indicate which processes should be executed for this PCBA.

The screenshot shows the 'Optional Processes' dialog box with the following sections and options:

- Component Prep:**
 - PCB Bake Out (Quantity: 0)
 - PCB Marking Labels (Quantity: 0)
 - PCB Marking Stencils (Quantity: 0)
 - Component Software Load (Components to Load (qty): 0)
- Surface Mount:**
 - Inputs active based on settings from previous screen
 - Solder Paste Inspection - Top
 - Solder Paste Inspection - Bottom
 - Automated Optical Inspection - Top
 - Automated Optical Inspection - Bottom
 - Automated XRay Inspection - Top
 - Automated XRay Inspection - Bottom
- Testing:**
 - Flying Probe Validation (FT Time (s): 0.00)
 - InCircuit Test (RF Time (s): 0.00)
 - Bake In Test (JTAG Time (s): 0.00)
 - Environmental Test
 - Functional Test (FT)
 - RF Test
 - Boundary Scan (JTAG)
 - HiPot Test (HiPot Time (s): 0.00)
 - Light Up Test (LUT) (LUT Testing Locations: 0)
 - Ion Chromatography (IC) (IC Method: dropdown)
 - Conformance Certification (CC) (Conf Cert Time (s): 0.00)
- Special Processes:**
 - Software Load (Sockets / Connectors: 0)
 - Revision Labels: 0
 - Software Load Time (s): 0.00
 - Conformal Coat (Method: dropdown)
 - Thickness Requirement Specified
 - Adhesive Staking (Adhesive types (qty): 0)
 - Adhesive Staking Locations: 0
 - Underfill (Underfill Locations: 0)
 - Potting (Potting Locations: 0)
- Final Assembly:**
 - Final Assembly
 - Manually Aligned Mechanical Components (qty): 0
 - Hardware Stackup Locations (qty): 0
 - Jumper Wires (qty): 0
 - Jumper Wire Staking Locations (qty): 0

The options in this dialog box map to each of the optional assembly processes documented later in this chapter. Use the following links to navigate to descriptions of these processes and their related Process Step Options (PSOs).

Component Prep:

- PCB Bake Out -- [Bake Out](#)
- PCB Marking Labels -- [Label](#)
- PCB Marking Stencils -- [Stencil](#)
- Component Software Load -- [Component Software Load](#)

Surface Mount:

- Solder Paste Inspection – Top -- [Solder Paste Inspection](#)
- Solder Paste Inspection – Bottom – [Solder Paste Inspection](#)
- Automated Optical Inspection -- Top -- [Automated Optical Inspection](#)
- Automated Optical Inspection -- Bottom -- [Automated Optical Inspection](#)

- Automated XRay Inspection -- Top -- [Automated Xray Inspection](#)
- Automated XRay Inspection -- Bottom -- [Automated Xray Inspection](#)

Testing:

- Flying Probe Validation -- [Flying Probe Validation](#)
- InCircuit Test -- [InCircuit Test](#)
- Bake In Test -- [Bake In Test](#)
- Environmental Test -- [Environmental Test](#)
- Functional Test (FT) -- [Functional Test](#)
- RF Test -- [RF Test](#)
- Boundary Scan (JTAG) -- [Boundary Scan](#)
- HiPot Test -- [HiPot Test](#)
- Light Up Test (LUT) -- [Light Up Test](#)
- ION Chromatography -- [Ion Chromatography](#)
- Conformance Certification -- [Conformance Certification](#)

Special Processes:

- Software Load (actually a “Testing” process) -- [Software Load](#)
- Conformal Coat -- [Conformal Coat](#)
- Adhesive Staking -- [Adhesive Staking](#)
- Underfill -- [Adhesive Underfill](#)
- Potting -- [Potting](#)
- **Final Assembly** (sub-category of Special Processes) -- [Final Assembly](#)

5 Click **OK** when done, then click **OK** on the **PCBA Costing** dialog box.

aPriori begins to cost the PCBA based on the inputs you have provided.

Note: When using the PCBA model for the first time, it's not uncommon to see one or more messages similar to “Could not find a feasible routing”. This typically indicates that aPriori could not find a match between a part in the BOM and the Component Library. Read the following sections for information about how to proceed.

To validate your initial costing

aPriori recommends that you validate your results, especially when first getting started with PCBA costing. This means manually checking for feasibility or costing errors, and checking the number of components in the assembly against the number of components listed on your PCBA BOM.

1 Common errors include:

- Something is not typed correctly.
- The component is missing from the Component Library (or it exists in the library but does not have a price, or is missing a type designation).

- The inputs you provided in the **PCBA Costing** dialog conflict with the data extracted from the BOM and Component Library. This typically involves the settings of **Surface Mount Sides** and **Plated Through Hole Sides**. For example, if your BOM contains no surface mount components but you specify **Single Sided** or **Double Sided** rather than **None**. Or conversely, if you specify **None**, yet your BOM contains components of the specified type.
- 2 Another adjustment that you can make would be to add additional operations that might not be called out explicitly on the original BOM. For example, labeling operations might not be in the BOM and therefore would not automatically show up in the **Assembly Details** tab. To manually add such an operation, bring up the **Routing Selection** editor by selecting the assembly and clicking **Edit > Routing Selection** in the **Manufacturing Process** panel). Add the missing process and adjust the quantity in the **Process Setting Options**. (For more information, see the "Selecting a process routing" section of the *aPriori User Guide*.)

Once you have successfully imported your PCBA, validated it, and obtained a reasonable initial costing, you can proceed to use it in aPriori in much the same way you would work with a geometry-based assembly and its component parts.

If you get a failed costing

If you get a failed costing due to a component or component cost missing from the Component Library, you can work around this failure:

For the short term, you can open the component and change it to a manually costed part and provide a material cost (if available) that will capture most of the cost impact of the missing component.

In parallel, you should contact your VPE manager/administrator who is responsible for maintaining and updating the Component Library to implement a permanent fix..

To recost an existing PCBA

In most cases, you should use the **PCBA** button to recost, following the same procedure described for importing and costing a new PCBA. Just select **Modify Current PCBA** when prompted. aPriori displays the costing dialog boxes populated with values that you entered from the previous costing.

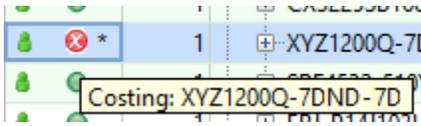
However, if you simply want to recost using different production settings (volume, batch size, etc.) and not vchange any other PCBA settings, it may be more efficient to use the standard **Cost Guide**. In this case, you would update the production settings, cost the assembly, copy the production volumes to the children, and then deep cost the assembly. See the *aPriori User Guide* for more information information about using the **Cost Guide** and assembly deep costing.

PCBA Processes – User Guided

The User Guided process group for PCBA provides component costs for purchased parts. These typically come from the Component Library, or are provided in the BOM.

In general, feasibility failures for components indicate that no cost could be found for the component, which means that an entry is missing or misspelled in the Component

Library. Hovering over the red x icon in the Assembly Details tab confirms a costing failure .



Expanding down to the Purchased Component row provides additional information.

PCBA Processes -- Assembly

PCBA assembly processes fall into the following general categories:

- Prep Processes
- Surface Mount
- Plated Through Hole
- Special Processing
- Testing

A common feasibility check for many processes is board size and weight: A machine may not be capable of handling the PCB if the PCB is not within the length, width, thickness and weight specifications of the machine.

Adhesive Dispense

Category: Surface Mount

Description: The automated application of an adhesive to the PCBA. This can be done by an in-line surface mount (SMT) machine which dispenses mechanical (e.g., “Loctite®”) or thermal (e.g., “Zymet”) adhesive to the surface of the PCB prior to component placement.(Also see [Adhesive Staking](#) and [Adhesive Underfill](#).)

Major Cost Drivers -- PCBA Adhesive Dispense

Adhesive Dispense Process Time is a sum of the time to load the Printed Circuit Board (PCB) into the machine from the input conveyor, move the PCB to the lock position in the machine and clamp it down, look at the fiducials on the PCB, purge the solder paste from the nozzle and calibrate if required, deposit paste dots onto the PCB, and unload the PCB from the solder jetter and output rail.

Process Time = (Load Time + Fiducial Check Time + Adhesive Dispense Time + Unload Time) / Panel Quantity

Load Time = Adhesive Dispenser Load Time

Adhesive Dispenser Load Time = (Machine variable)

Fiducial Check Time = (Machine variable)

Adhesive Dispense Time = Dot Count / Dot Deposition Rate

Dot Count = Chip Dot Count*Qty SMChipComponents + Integrated Circuit Dot Count* (Qty SM Integrated Circuit Components + Qty SM Fine Pitch Components)

Chip Dot Count = (Machine variable)

Integrated Circuit Dot Count = (Machine variable)

Dot Deposition Rate = (Machine variable)

Unload Time = (Output Conveyor Length/Output Conveyor Speed) + Adhesive Dispenser Unload Time

Output Conveyor Length = (Machine variable)

Output Conveyor Speed = (Machine variable)

Adhesive Dispenser Unload Time = (Machine variable)

Load Time is the time to load the PCB into the machine input conveyor from the output conveyor of the previous machine (Screen Printer, Solder Jetter, or Solder Paste Inspection).

Fiducial Check Time is the time to look at the PCB alignment marks (fiducials).

Adhesive Dispense Time is the time to dispense adhesive onto PCB based on Dot Count (as specified in the component BOM) and the Dot Speed of the machine.

Unload Time is calculated from the machine unload time and the length and speed of the conveyor after Adhesive Dispense.

User Inputs – PCBA Adhesive Dispense

N/A

Adhesive Staking

Category: Special Processing

Description: The automated application of a staking adhesive to the PCBA to secure components to the PCB surface. For example, components exceeding a certain weight might be bonded to the PCB when no other mechanical support is used.

Major Cost Drivers -- PCBA Adhesive Staking

The **Cycle Time** for PCBA Adhesive Staking is the time to prepare the material(s), apply the adhesive through a syringe to the location, load into the oven, cure the material, and then unload from the oven.

Process Time = Adhesive Prep Time + Adhesive Apply Time + Adhesive Curing Time

Adhesive Prep Time = Adhesive Quantity * Material Prep Time

Adhesive Quantity = (PSO)

Material Prep Time = (Machine variable)

Adhesive Apply Time = Adhesive Locations * Adhesive Stake Time

Adhesive Locations = (PSO)

Adhesive Stake Time = (Machine variable)

Adhesive Curing Time = Load Time + Oven Time

Load Time = Oven Load Time + Oven Unload Time

Oven Load Time = (Machine variable)

Oven Unload Time = (Machine variable)

Oven Time = (Machine variable) * SEC_PER_HR

User Inputs – PCBA Adhesive Staking

PSO: Adhesive Quantity: The number of different adhesive types used.

PSO: Adhesive Locations: The number of locations to which to apply the adhesive.

Adhesive Underfill

Category: Special Processing

Description: The manual or automated application of adhesive between the underside of a component and the PCB. This prevents the introduction of dust, debris, salt, etc. between the component and the PCB. The underfill also masks between the component body and PCB prior to conformal coat.

Major Cost Drivers -- PCBA Adhesive Underfill

The **cycle time** used to underfill components on a PCBA is the time to prepare the material(s), apply the adhesive through a syringe to the location and have it flow under the part, load into the oven, cure the material, and unload from the oven.

Process Time = Underfill Prep Time + Underfill Apply Time + Adhesive Curing Time

Underfill Prep Time = Material Prep Time (Machine variable)

Underfill Apply Time = Underfill Locations * Underfill Flow Time

Underfill Locations = Number of Underfill Locations (PSO)

Underfill Flow Time = (Machine variable)

Adhesive Curing Time = Oven Load Time + Oven Unload Time + Oven Time

Oven Load Time = (Machine variable)

Oven Unload Time = (Machine variable)

Oven Time = (Machine variable)

User Inputs -- PCBA Adhesive Underfill

PSO: Number of Underfill Locations

Automated Optical Inspection**Category: Surface Mount**

Description: Automated optical inspection (AOI) is an automated visual inspection of printed circuit boards (PCBs) or individual components (such as LCDs, transistors, etc.). A camera autonomously scans the device under test for both catastrophic failure (such as a missing component) and quality defects (such as incorrect fillet size or shape or component skew). It is commonly used in the manufacturing process because it is a non-contact test method. It is implemented at many stages through the manufacturing process including bare board inspection, solder paste inspection (SPI), pre-reflow and post-reflow, as well as other stages.

By default, AOI is immediately after SMT Placement, though it may be physically performed after Reflow or after Manual Assembly operations. If necessary, customization can be performed in the VPE to move the AOI operation. The impact to labor should be negligible.

Major Cost Drivers -- PCBA Automated Optical Inspection

Automated Optical Inspection (AOI) cycle time is the time to load the PCBA into the machine, clamp the PCBA, check the fiducials, move the camera over the PCBA, and unload the PCBA from the machine. This model assumes that the time the camera requires to change direction during the scanning process is negligible.

Process Time = Load Time + Fiducial Check Time + Automated Optical Inspection Time + Unload Time

Load Time = Input Conveyor Length/Input Conveyor Speed + Machine Load Time

Input Conveyor Length = (Machine variable)

Input Conveyor Speed = (Machine variable)

Machine Load Time = (Machine variable)

Fiducial Check Time = (Machine variable)

Automated Optical Inspection Time = PCB Area/ Scanning Speed

PCB Area = PCB Width * PCB Length

PCB Width =(Global Input)

PCB Length = (Global Input)

Scanning Speed = (Machine variable)

Unload Time = Output Conveyor Length/Output Conveyor Speed + Machine Unload Time

Output Conveyor Length = (Machine variable)

Output Conveyor Speed = (Machine variable)

Machine Unload Time = (Machine variable)

User Inputs -- PCBA Automated Optical Inspection

N/A

Automated Xray Inspection

Category: Surface Mount

Description: Automated Xray Inspection (AXI) is similar to (but more costly than) Automated Optical Inspection (AOI), since it uses X-rays rather than visible light to automatically inspect features that are typically hidden from view.

For example, integrated circuits with packages such as BGAs (ball grid array) have connections that are underneath the chip and not visible, so that ordinary optical inspection is impossible. Because the connections are underneath the chip package there is a greater need to ensure that the manufacturing process is able to accommodate these chips correctly. Additionally, chips that use BGA packages tend to be larger ones with many connections. Therefore it is essential that all the connections are made correctly. AXI can identify find faults such as opens, shorts, insufficient solder, excessive solder, missing electrical parts, and mis-aligned components in these difficult-to-access locations..

AXI is often paired with the testing provided by [Boundary Scan](#), [InCircuit Test](#), and [Functional Test](#).

Major Cost Drivers -- PCBA Automated Xray Inspection

Cycle Time for Automated Xray Inspection is the time required to load the PCBA into the machine, clamp the PCBA, check fiducials or tooling alignment holes, move to the x-ray locations, generate a results report, and unload the PCBA from the machine.

Process Time = Load Time + Fiducial Check Time + Automated Xray Inspection Time + Unload Time /panelizationQuantity

Load Time = Input Conveyor Length/Input Conveyor Speed + Automated Xray Inspection Load Time

Input Conveyor Length = (Machine variable)

Automated Xray Inspection Load Time = (Machine variable)

Fiducial Check Time = (Machine variable)

Automated Xray Inspection Time = PCB Area/Scanning Speed

PCB Area = PCB Width * PCB Length

PCB Width = (Global Input)

PCB Length =(Global Input)

Scanning Speed = (Machine variable)

Unload Time = Output Conveyor Length/Output Conveyor Speed + Automated Xray Inspection Unload Time

Output Conveyor Length = (Machine variable)

Output Conveyor Speed = (Machine variable)

Automated Xray Inspection Unload Time = (Machine variable)

User Inputs -- PCBA Automated Xray Inspection

N/A

Bake In Test

Category: Testing

Description: Bake In Test (also known as “Burn-in”) is the process by which a PCBA is subjected to elevated temperature to force certain failures to occur under supervised conditions during the manufacturing process, to prevent failure in the field.

When possible, it is better to eliminate the root cause of early failures than doing a burn-in. Because of this, a process that initially uses burn-in may eventually phase it out as the various root causes for failures are identified and eliminated.

Major Cost Drivers -- PCBA Bake In Test

Bake-In **Cycle Time** is the summation of the time to load the heat profile on the oven chamber, load the PCBA, unload the PCBA, and inspect the PCBA. We assume that zero monitoring time is required.

Process Time = Profile Load Time + Board Load Time + Board Unload Time + Board Inspect Time

Profile Load Time = (Machine variable)

Board Load Time = (Machine variable)

Board Unload Time = (Machine variable)

Board Inspect Time = (Machine variable)

User Inputs -- PCBA Bake In Test

N/A

Bake Out

Category: Prep Processes >PCB Prep

Description: Bake-out is a PCB preparation process to remove moisture prior to proceeding to other processes.

Major Cost Drivers -- PCBA Bake Out

Bake Out cycle time includes the time to load the oven profile, load the PCB, unload, and inspect.

Process Time = (Profile Load Time/Batch Size) + Board Load Time + Board Unload Time + Board Inspect Time

Profile Load Time = (Machine variable)

Board Load Time = (Machine variable)

Board Unload Time = (Machine variable)

Board Inspect Time = (Machine variable)

User Inputs -- PCBA Bake Out

N/A

Batch Wash

Category: Special Processing

Description: The Batch Wash process removes post-soldering contaminants from the PCBA. This typically takes place in a separate machine and typically involves one or more water or water-with-chemical “spray in air” operations. See also: [Hand Wash](#), [Inline Wash](#).

Major Cost Drivers -- PCBA Batch Wash

Batch Wash **Cycle Time** includes the time it takes to load the PCBAs into the batch washer, run the batch wash and unload the batch wash.

Process Time = Load Time + Batch Wash Time + Unload Time

Load Time = (Machine variable)

Batch Wash Time = (Machine variable)

Unload Time = (Machine variable)

User Inputs -- PCBA Batch Wash

Process-specific: N/A

Global Inputs: PCB Length, PCB Width, PCB Thickness, PCB Weight

Boundary Scan

Category: Testing

Description: Boundary Scan is a method for testing PCBA interconnects without using physical test probes. The board and key components on the board must have been designed to support Boundary Scan.

Major Cost Drivers -- PCBA Boundary Scan

Boundary Scan **Cycle Time** is the time required to run the boundary scan for the specific PCBA. This is a machine rate that can be customized in the VPE.

Process Time = Boundary Scan Test Time

Boundary Scan Test Time = (PSO)

Hard Tooling Cost = Boundary Scan (JTAG) Equipment Cost

Boundary Scan (JTAG) Equipment Cost = (PSO)

User Inputs -- PCBA Boundary Scan

PSO: Boundary Scan Test Time

PSO: Boundary Scan (JTAG) Equipment Cost

Component Prep Automated

Category: Prep Processes > Component Prep

Description: Automated Component Prep is the process of having a machine form component leads prior to insertion in the PCB.

Major Cost Drivers -- PCBA Component Prep Automated

Component Prep Automated **Cycle Time** is a function of the number of component leads that need to be preformed times the machine press time to form the lead.

If PSO Auto Prep Method = Bench Press:

Process Time = Number of Auto-Preformed Leads*Press Time

Number of Auto-Preformed Leads = (PSO)

If PSO Auto Prep Method = Sequencer:

Process Time = Number of Auto-Preformed Parts*Press Time

Number of Auto-Preformed Parts = (PSO)

User Inputs -- PCBA Component Prep Automated

PSO: Auto Prep Method (Bench Press or Sequencer)

PSO: Number of Auto-Preformed Leads

PSO: Number of Auto-Preformed Parts

Component Prep Manual

Category: Prep Processes > Component Prep

Description: Manual Component Prep is the process of forming component leads by hand prior to insertion in the PCB.

Major Cost Drivers -- PCBA Prep Manual

Manual Component Prep **Cycle Time** is a function of the number of component leads that need to be preformed by hand.

Process Time = Number of Manual Preformed Leads*Lead Preform Time

Number of Manual Preformed Leads = (PSO)

Lead Preform Time = (Machine variable)

User Inputs -- PCBA Prep Manual

PSO: Number of Manual Preformed Leads

Component Software Load

Category: Prep Processes > Component Prep

Description: The Component Software Load process loads firmware onto an individual electronic component. The default software load machine is one computer with multiple connectors to program multiple different devices through those different connector locations.

Major Cost Drivers -- PCBA Component Software Load

Component Software Load **Cycle Time** is the time it takes to mate sockets.

// Process Time to relabel programmed part, mate sockets, and perform software load.

processTime = ((Label Print Time*Software Revision Label Quantity)/Batch Size) + (Label Install Time*Software Revision Label Quantity) + (Socket Mate Time*Components to Load Quantity) + Software Load Time

Label Print Time = (Machine Variable)

Label Install Time = (Machine Variable)

Label Install Time = (Machine Variable)

Socket Mate Time = (Machine Variable)

Components to Load Quantity = (PSO)

Software Load Time = (Machine Variable)

User Inputs -- PCBA Component Software Load

PSO: Components to Load Quantity

Conformal Coat

Category: Special Processing

Description: Conformal coating applies a film that 'conforms' to the contours of a PCB to protect its components against moisture, dust, chemicals, and temperature extremes. The coating can be applied by a variety of methods.

Major Cost Drivers -- PCBA Conformal Coat

Conformal Coat **Cycle Time** is the sum of the time to mask the locations that should not be coated, apply the conformal coat, remove the masking material, inspect the conformal coat, and touch up missing areas that need to be coated.

// Process Time to perform Conformal Coat.

Process Time = Masking Time + Conformal Coat Time + Demasking Time + Inspect Time + Touch Up Time

Masking Time = Masking Boot Install Time + Masking Die Cut Install Time + Masking Seal And Peel Install Time + Masking Tape Install Time

Masking Boot Install Time = Masking Boot Quantity* Masking Boot Install Time

Masking Boot Quantity = (PSO)

Masking Boot Install Time = (Machine variable)

Masking Die Cut Install Time = Masking Die Cut Quantity* Masking Die Cut Install Time

Masking Die Cut Quantity = (PSO)

Masking Die Cut Install Time = (Machine variable)

Masking Seal And Peel Install Time = Masking Seal And Peel Quantity* Masking Seal And Peel Install Time

Masking Seal And Peel Quantity = (PSO)

Masking Seal And Peel Install Time = (Machine variable)

Masking Tape Install Time = Masking Tape Quantity* Masking Tape Install Time

Masking Tape Quantity = (PSO)

Masking Tape Install Time = (Machine variable)

Conformal Coat Time =

**If PSO "Method of Conformal Coat" = Hand Spray:
Hand spray: {(PCB Length* PCB Width)/(Hand Spray Deposition Rate)**

PCB Length = (Global Input)

PCB Width = (Global Input)

Hand Spray Deposition Rate = (Machine variable)

If PSO "Method of Conformal Coat" = Machine Spray:

Machine spray: Machine Spray Load Time + Machine Spray Unload Time

Machine Spray Load Time = (Machine variable)

Machine Spray Unload Time = (Machine variable)

If PSO “Method of Conformal Coat” = Hand Brush:
Hand brush: Hand Brush (PCB Length* PCB Width)/(Hand Brush Deposition Rate)

Hand Brush Deposition Rate = (Machine variable)

If PSO “Method of Conformal Coat” = Machine Vapor Deposition:
Machine Vapor Deposition: Vapor Deposition Load Time +Vapor Deposition Unload Time

Vapor Deposition Load Time = (Machine variable)

Vapor Deposition Unload Time = (Machine variable)

Demasking Time = (Masking Boot Quantity + Masking Die Cut Quantity + Masking Seal And Peel Quantity + Masking Tape Quantity)* Mask Removal Time

Masking Boot Quantity = (PSO)

Masking Die Cut Quantity = (PSO)

Masking Seal And Peel Quantity = (PSO)

Masking Tape Quantity = (PSO)

Mask Removal Time (Machine variable)

Inspect Time = (Machine variable)

Touch Up Time = (Machine variable)

User Inputs -- PCBA Conformal Coat

PSO: Method of Conformal Coat (Machine Spray, Machine Vapor Deposition, Hand Spray, Hand Brush)

PSO: Quantity of Masking Boots (for test points/connectors)

PSO: Quantity of Die Cut Masking Locations (for potentiometers/keep-out areas)

PSO: Quantity of Seal And Peel Locations (for connectors)

PSO: Quantity of Masking Tape locations (for borders and keep-out areas)

Global Inputs: PCB Length, PCB Width

Conformance Certification

Category: Testing

Description: This process covers the generation of documentation certifying compliance to assembly specifications. Conformance certification requires drawings either in paper or digital format as well as the log associated with the PCBA (either paper or digital). This is standard factory equipment and no special equipment is required.

Major Cost Drivers -- PCBA Conformance Certification

Conformance Certification Cycle Time is the time required to perform the conformance certification. If this is a first article inspection the time may take 60 minutes. Typical time would be 15 minutes.

Process Time = Conformance Certification Time

Conformance Certification Time = (PSO)

User Inputs -- PCBA Conformance Certification

PSO: Conformance Certification Time

Depanelization

Category: Special Processing

Description: This process covers the manual or automated separation of a PCB from a panel multiple PCBs.

Major Cost Drivers -- PCBA Depanelization

Cycle Time depends on the method selected. If there are breakaway tabs, this is the time to break the tabs and file them down. If a PCB band saw is available, the process is automated and is a factor of the perimeter of the PCB by the rate of speed of the PCB depaneling band saw.

If PSO Depanelization Method = Manual:

Process Time = {(Tab Quantity*(Break Away Time + File Time))

If PSO Depanelization Method = Automated:

Process Time = ((PCB Length+PCB Width)*2)/Band Saw Rate

Tab Quantity = (PSO)

Break Away Time = (Machine variable)

File Time = (Machine variable)

PCB Length = (Global Input)

PCB Width = (Global Input)

Band Saw Rate = (Machine variable)

User Inputs -- PCBA Depanelization

PSO: Depanelization Method (Manual or Automated)

Environmental Test

Category: Testing

Description: This verifies that the PCB can withstand the rigors of harsh environments such as temperature extremes, sand, moisture, etc.

Major Cost Drivers -- PCBA Environmental Test

Environmental Test **Cycle Time** is the summation of the time to load the heat profile on the oven chamber, load the PCBA, unload the PCBA, and inspect the PCBA. We are assuming that zero monitoring time is required.

Process Time = Profile Load Time + Board Load Time + Board Unload Time + Board Inspect Time

Profile Load Time = (Machine variable)

Board Load Time = (Machine variable)

Board Unload Time = (Machine variable)

Board Inspect Time = (Machine variable)

User Inputs -- PCBA Environmental Test

N/A

Final Assembly**Category: Special Processing**

Description: -- Final Assembly consists of processes that must be performed by hand, such as positioning hardware parts, installing jumper wires, and staking those wires.

Major Cost Drivers – Final Assembly

// Process Time for final assembly manual processes.

Process Time = Final Assembly Install Process Time + Wire Install Process Time

Final Assembly Install Process Time = (Final Assembly Align Time* Final Assembly Quantity) + Hardware Install Time

Final Assembly Quantity = (PSO)

Final Assembly AlignTime = (Machine variable)

Hardware Install Time = Hardware Stackup Locations* Hardware Stackup Install Time

Hardware Stackup Locations = (PSO)

Hardware Stackup InstallTime = (Machine variable)

//Jumper wire installation. Note: One end will be soldered and the other end will be assembled in hardware stackup.

Wire Install Process Time = ((Jumper Wire Cut Time + Jumper Wire Strip Time + Jumper Wire Solder Time)* Jumper Wire Quantity) + Jumper Wire Staking Time + Jumper Wire Curing Time

Jumper Wire Cut Time = (Machine variable)

Jumper Wire Quantity = (PSO)

Jumper Wire Strip Time = (Machine variable)

Jumper Wire Solder Time = (Machine variable)

Jumper Wire Staking Time = (Staking Mix Time /Batch Size) + (Jumper Wire Staking Time * Jumper Wire Staking Locations) //If “Is Jumper Wire Staking Required” = true

Is Jumper Wire Staking Required = (PSO)

Jumper Wire Staking Time = (Machine variable)

Staking Mix Time = (Machine variable)

Jumper Wire Staking Locations = (PSO)

Jumper Wire Curing Time = ((Load Time + Oven Time)/Batch Size) //If “Is Jumper Wire Staking Required” = true

Load Time = Oven Load Time + Oven Unload Time

Oven Load Time = (Machine variable)

Oven Unload Time = (Machine variable)

Oven Time = (Machine variable) * SEC_PER_HR

User Inputs -- Final Assembly

PSO: Quantity of Parts to be Manually Aligned to PCB (Frames, Heatsinks, Shunts, Fences, etc.)

PSO: Quantity of Hardware Stackup Locations

PSO: Quantity of Jumper Wires

PSO: Is Jumper Wire Staking Required?

PSO: Quantity of Jumper Wire Staking Locations

Final Assembly Component Setup

Category: Special Processing

Description: This is an optional process for capturing the time and cost associated with creating kits for the final assembly processes. The Final Assembly Component Setup process can be included manually via the **Routing Editor** or the **Optional Secondary Processes** dialog.

Flying Probe Validation

Category: Testing

Description: Flying probe validation typically tests basic production, prototypes, and boards by using electro-mechanically controlled probes to access components that present accessibility problems.

Process is optional and is turned OFF by default.

Major Cost Drivers -- PCBA Flying Probe Validation

Flying probe **Cycle Time** is a sum of the board load time, flying probe time, and Board Unload time. Flying probe time is a function of the number of pins divided by the rate of the machine checking these pins.

Process Time = Board Load Time + Flying Probe Time + Board Unload Time

Board Load Time = (Machine variable)

Flying Probe Time = Qty of Pins / Flying Probe Rate

Flying Probe Rate = (Machine variable)

Board Unload Time = (Machine variable)

User Inputs -- PCBA Flying Probe Validation

N/A

Functional Test

Category: Testing

Description: Functional test ("FCT") is typically performed in the last phase of the production line of a product, as a final quality control by emulating or simulating the operational environment of the product in order to check its correct functionality. Unlike [InCircuit Test](#) which uses test points on the PCB, Functional Test uses the PCB connectors for test software to communicate between the PCB and external programmable instruments.

Major Cost Drivers -- PCBA Functional Test

Functional Test **Cycle Time** is a factor of the planned functional test time and the test yield.

Process Time = Functional Test Time*(Functional Test Yield/100)

Functional Test Time =(PSO)

Hard Tooling Cost = Functional Test Equipment Cost

Functional Test Equipment Cost = PSO)

User Inputs -- PCBA Functional Test

PSO: Functional Test Time

PSO: Functional Test Yield

PSO: Functional Test Equipment Cost

Hand Wash

Category: Special Processing

Description: The Hand Wash process removes post-soldering contaminants from the PCBA by hand cleaning with alcohol and brush. Hand Wash of PCBAs is normally reserved for light rework, and is not generally recommended for primary cleaning. See also: [User Inputs](#) — PCBA Bake Out

N/A

Batch Wash, [Inline Wash](#).

Major Cost Drivers -- PCBA Hand Wash

Hand Wash **Cycle Time** is the time required to transport cleaning materials to the work area and perform manual cleaning with alcohol and brush.

Process Time = Transport Time + Hand Wash Time

// Time to transport and refresh cleaning materials.

Transport Time = (Machine variable)

// Time to hand wash.

Hand Wash Time = (Machine variable)

User Inputs -- PCBA Hand Wash

Process-specific: N/A

Global Inputs: PCB Length, PCB Width, PCB Thickness, PCB Weight

Heat Sink Install

Category: Special Processing

Description: This is the process to assemble heat sink devices or materials onto a PCB Assembly. This may be an assembly with a fan on it to drive heat away from the assembly or metal plates that will dissipate heat from the assembly. Both of these require thermal compound to be applied in between the device and the PCB as air is not a good conductor of heat. The thermal compound facilitates the cooling of the assembly through the heat sink.

Major Cost Drivers -- PCBA Heat Sink Install

Heat Sink Install **Cycle Time** is a compilation of the time to apply thermal compound, align the heatsinks and install any hardware that may accompany the heat sinks.

Process Time = ((Thermal Compound Time + Heat Sink Align Time)*Heat Sink Quantity) + Hardware Install Time

Thermal Compound Time = Thermal Compound Prep Time + Thermal Compound Apply Time

Thermal Compound Prep Time = (Machine variable)/Batch Size

Thermal Compound Apply Time = (Machine variable)

Heat Sink Align Time = (Machine variable)

Heat Sink Quantity = (PSO)

Hardware Install Time = Hardware Stackup Locations*Hardware Stackup Install Time

Hardware Stackup Locations = (PSO)

Hardware Stackup Install Time = (Machine variable)

User Inputs -- PCBA Heat Sink Install

PSO: Heat Sink Quantity

PSO: Hardware Stackup Locations

HiPot Test

Category: Testing

Description: HiPot Test checks for "good isolation", ensuring that no current flows between points where there should be no current.

HiPot tests are helpful in finding

- nicked or crushed insulation
- stray wire strands or braided shielding
- conductive or corrosive contaminants around the conductors
- terminal spacing problems
- tolerance errors in IDC cables

There are three common high voltage tests.

- Dielectric Breakdown Test ("How much voltage can I apply between the wires before the insulation fails?")
- Dielectric Withstanding Test ("Will this cable withstand a required voltage for a required time?")
- Insulation Resistance Test ("Is the resistance of the insulation high enough?")

Process is optional and is turned OFF by default.

Major Cost Drivers -- PCBA HiPot Test

HiPot Test **Cycle Time** is specific to PCBA design and is therefore entered as a PSO.

Process Time = HiPot Test Time

$$\text{HiPot Test Time} = (\text{PSO})$$

Hard Tooling Cost = HiPot Test Equipment Cost

$$\text{HiPot Test Equipment Cost} = (\text{PSO})$$

User Inputs -- PCBA HiPot Test

PSO: HiPot Test Time

PSO: HiPot Test Equipment Cost

InCircuit Test**Category: Testing**

Description: InCircuit Test (ICT) is a process for testing PCBAs using probes to identify faults such as shorts or opens, or incorrect values in resistance, capacitance, etc.

Process is optional and is turned OFF by default.

Major Cost Drivers -- PCBA InCircuit Test

InCircuit Test **Cycle Time** is the product of the component quantities and the time the machine takes to test those components.

Process Time = Load Time + Test Time + Unload Time

$$\text{Load Time} = (\text{Machine variable})$$

$$\text{Test Time} = \text{Quantity of components} / \text{Test Rate}$$

$$\text{Test Rate} = (\text{Machine variable})$$

$$\text{Unload Time} = (\text{Machine variable})$$

User Inputs -- PCBA InCircuit Test

Process-specific: N/A

Global Inputs: PCB Length, PCB Width, PCB Thickness.

Inline Wash**Category: Surface Mount**

Description: The InLine Wash process removes post-soldering contaminants from the PCBA. Unlike [User Inputs](#) -- PCBA Bake Out

N/A

Batch Wash, and [Hand Wash](#). InLine Wash occurs within the production line where a wash, rinse, dry cycle occurs.

Major Cost Drivers -- PCBA Inline Wash

Inline Wash **Cycle Time** is the time it takes for the PCBA to travel through the Inline Wash machine and then be unloaded.

Process Time = Inline Wash Time + Unload Time**Inline Wash Time = Inline Wash Length/Inline Wash Speed****Inline Wash Length = (Machine variable)****Inline Wash Speed = (Machine variable)****Unload Time = Output Conveyor Length/Output Conveyor Speed****Output Conveyor Length = (Machine variable)****Output Conveyor Speed = (Machine variable)****User Inputs -- PCBA Inline Wash**

Process-specific: N/A

Global Inputs: PCB Length, PCB Width, PCB Thickness, PCB Weight

Ion Chromatography

Category: Testing

Description: Ion Chromatography is an advanced, highly-accurate test process to identify contaminants on a PCBA which could lead to failure over time in the field, such as shorts between closely-spaced pads due to dendritic growth.

Process is optional and is turned OFF by default.

Major Cost Drivers -- PCBA Ion Chromatography

Ion Chromatography **Cycle Time** is either the sum of a total immersion in water, or a sum of testing specific locations.

If PSO Ion Chromatography Method = Full Immersion:

Full Immersion Process Time = Board Load Time + ((Ion Chromatography Run Time)*(MonitorPercentage/100)) + Board Unload Time + Board Inspect Time

If PSO Ion Chromatography Method = Spot Test:

Spot Test Process Time = Board Load Time + ((Ion Chromatography Run Time*Ion Chromatography Spot Test Quantity)*(Monitor Percentage/100))+ Board Unload Time + Board Inspect Time

Board Load Time = (Machine variable)**Board Unload Time = (Machine variable)****Board Inspect Time = (Machine variable)****Ion Chromatography Run Time = (Machine variable)****Ion Chromatography Spot Test Quantity = (Machine variable)****Monitor Percentage = (Machine variable)****User Inputs -- PCBA Ion Chromatography**

PSO: Ion Chromatography Method (Full Immersion or Spot Test)

Jumper Wire Install

Category: Special Processing

Description: This process covers the manual installation of jumper wires on a PCB. Depending on the purpose, location, and length of the jumper, several different factors may need to be considered to provide an accurate costing. These factors can include prep time, dressing, staking, method of attachment, application of insulation, drilling of new holes, etc.

Major Cost Drivers -- PCBA Jumper Wire Install

Jumper Wire Installation **Cycle Time** is the time required to prep the jumper wires, solder them into place, and stake them if required. Staking is required every 1 inch or at every routing turn, or as directed by the PCB assembly drawing. This cannot be automated therefore user input is required.

Process Time = ((Jumper Wire Cut Time + Jumper Wire Strip Time*2 + Jumper Wire Solder Time*2)* Jumper Wire Quantity) + Jumper Wire Staking Time + Jumper Wire Curing Time

Jumper Wire Cut Time = (Machine variable)

Jumper Wire Quantity = (Machine variable)

Jumper Wire Strip Time = (Machine variable)

Jumper Wire Solder Time = (Machine variable)

//Jumper Wire Staking Time is computed only if PSO Jumper Wire Staking Required is true.

Jumper Wire Staking Time = { (Staking Mix Time/Batch Size) + (machine. Jumper Wire Staking Time*setup. Jumper Wire Staking Locations

Staking Mix Time = (Machine variable)

Jumper Wire Staking Time = (Machine variable)

Jumper Wire Staking Locations = (PSO)

Jumper Wire Curing Time = Load Time + Oven Time

Load Time = Oven Load Time + Oven Unload Time

Oven Load Time = (Machine Variable)

Oven Unload Time = (Machine Variable)

Oven Time = (Machine variable)*SEC_PER_HR

User Inputs -- PCBA Jumper Wire Install

PSO: Jumper Wire Quantity

PSO: Jumper Wire Staking Required

PSO: Jumper Wire Staking Locations

Label

Category: Prep Processes > PCB Prep

Description: Label is a PCBA prep processes for printing and applying labels to the PCB with information such as PCBA Part Number, Serial Number, Date Code, ESD Marking, "Bad Board" Marking, etc..

Major Cost Drivers -- PCBA Label

Label Cycle Time includes the time to print the labels and apply the labels to the PCB surface (or to the piece parts that require them).

Process Time = (Label Print Time/Batch Size) + (Label Install Time*Label Quantity)

Label Print Time = (Machine variable)

Label Install Time = (Machine variable)

Label Quantity = (PSO)

User Inputs -- PCBA Label

PSO: Label Quantity.

Light Up Test**Category: Testing**

Description: Light Up Test is a simple process to detect the presence or absence of voltage at a particular point in the PCBA.

Major Cost Drivers -- PCBA Light Up Test

Light Up Test **Cycle Time** is the product of the amount of time it takes to test each location and the number of locations that need to have the light up test performed.

Process Time = Light Up Test Location Run Time*Light Up Test Location Quantity

Light Up Test Location Run Time = (PSO)

Light Up Test Location Quantity = (PSO)

User Inputs -- PCBA Light Up Test

PSO: Light Up Test Location Run Time

PSO: Light Up Test Location Quantity

PCB Flip

Category: Surface Mount > Surface Mount Double-Sided > Surface Mount Second Side

Description: PCB Flip is an optional process used for two-sided Surface Mount (SMT) PCBs to reorient the board for work on the second side after the first side has been completed.

Major Cost Drivers -- PCBA Flip

PCB Flip **Cycle Time** is the time it takes the machine to flip the part.

Process Time = (Flip Time)/Panelization Quantity

Flip Time = (Machine variable)

Panelization Quantity = (Global Input)

User Inputs -- PCBA Flip

Process-specific: N/A

Global inputs: Panelization Quantity

PCB Load

Category: Surface Mount

Description: The PCB load process is the automated feeding of the assembly line by using a Bare Board Unstacker, or equivalent machine. A stack of bare PCBs is loaded into a magazine or directly onto the unstacker, depending on the specific unstacker model. A plunger may push the PCB into the line, or the PCB may drop from the stack onto the conveyor.

Major Cost Drivers -- PCBA PCB Load

PCB Load **Cycle Time** is the sum of time to unload the PCB from the stack of PCBs (Unstacker Time), the time to transport across the length of the unstacker machine (Transport Time), and the time to reload the unstacker with a stack of PCBs (Reload Unstacker Time). Note that there is a weight and height limit of the stack that the machine can accept, therefore the Cost Model must look for the lowest integer between the maximum capacity based on height and the maximum capacity based on weight. Based on this capacity, we can determine how many times per batch the reload will need to happen and we distribute this time evenly across the batch, assuming that the impact of this time is only required to determine costing and is not critical to determine line balancing.

// Process Time for PCB unstacker to feed SMT line.

Process Time = Unstacker Time + Transport Time + (Reload Unstacker Time/Batch Size)

// Time for one PCB to unstack.

Unstacker Time = (Machine variable)

// Transport time through inspection station.

Transport Time = Unstacker Conveyor Length/Unstacker Conveyor Speed

Unstacker Conveyor Length = (Machine variable)

Unstacker Conveyor Speed = (Machine variable)

// Time to reload stacker.

Reload Unstacker Time = (Roundup(Batch Size/Unstacker Capacity))*Reload Time

Unstacker Capacity = min(rounddown(Max Stack Height/PCB Thickness), rounddown(Max Stack Weight/PCB Weight))

Max Stack Height = (Machine variable)

PCB Thickness = (Global Input)

Max Stack Weight = (Machine variable)

PCB Weight = (PSO)

Reload Time = (Machine variable)

User Inputs -- PCBA PCB Load

Process specific: N/A

Global Inputs: PCB Length, PCB Width, PCB Thickness, PCB Weight.

PEMS

Category: Prep Processes > Component Prep

Description: PEMS are Plastic Encapsulated Microcircuits. These microcircuits are susceptible to moisture exposure and therefore must be sealed in an airtight plastic bag with desiccant when not in use. In certain circumstances PEMS must be subjected to a bake process are required to be baked before installation onto the PCBA. There are different levels of sensitivity and these are determined by the vendor. Level 1 is common and does not require bake out. Level 2 through Level 5A have different levels of exposure that they can be out of these sealed bag or a dry box for.

Major Cost Drivers -- PCBA PEMS

PEMS **Cycle Time** is the time required to unpackage, bake (when required), and reseal PEMS components for the specific PCBA.

Process Time = (Unpackage Time + Bake Out Time + Reseal Time)*qty PEMS Part Types

Unpackage Time = (Machine variable)

Bake Out Time = (Machine variable)

Reseal Time = (Machine variable)

User Inputs -- PCBA PEMS

N/A

Potting

Category: Special Processing

Description: Potting is the process of filling a complete electronic assembly with a solid or gelatinous compound for resistance to shock and vibration, and for exclusion of moisture and corrosive agents.

Selective potting is used to seal specified areas, where the potting is contained by a bondline or mechanical border.

Note: Most circuit board assembly houses coat assemblies with a layer of transparent conformal coating rather than potting. Conformal coating gives most of the benefits of potting, and is lighter and easier to inspect, test, and repair. See: [Component Software Load](#).

Major Cost Drivers -- PCBA Potting

Potting **Cycle Time** is comprised of masking the component or PCBA, mixing the potting material, applying it, curing it, inspecting it and touching it up.

Process Time = Masking Time + Mixing Time + Potting Time + Curing Time + Demasking Time + Inspect Time + Touch Up Time

Masking Time = Potting Location Quantity * Masking Tape Install Time

Potting Location Quantity = (PSO)

Masking Tape Install Time = (Machine variable)

Mixing Time = (Machine variable)/Batch Size

Potting Time = (Machine variable)

Curing Time = Load Time + Oven Time

Load Time = Oven Load Time + Oven Unload Time

Oven Load Time = (Machine variable)

Oven Unload Time = (Machine variable)

Oven Time = (Machine variable)*SEC_PER_HR

Demasking Time = Potting Location Quantity * Mask Removal Time

Mask Removal Time = (Machine variable)

Inspect Time = (Machine variable)

Touch Up Time = (Machine variable)

User Inputs -- PCBA Potting

PSO: Potting Location Quantity

PTH Auto Insert

Category: Plated Through Hole

Description: The PTH Auto Insert is the process of having a machine populate a PCB with Plated Through Hole components. (See also: [PTH Hand Install](#))

Major Cost Drivers -- PCBA PTH Auto Insert

PTH Auto Insert **Cycle Time** is the sum of the time to load the machine, check the positioning of the PCB (using fiducial markings), have the machine insert the components, and then unload the machine.

Process Time = (Auto Insert Process Time)/Panelization Quantity

Auto Insert Process Time = Load Time + Fiducial Check Time + Auto Insert Placement Time + Unload Time

Load Time = (Machine variable)

Fiducial Check Time = (Machine variable)

Auto Insert Placement Time = Qty TH Auto Insert Components/Auto Insert Deposition Rate

Auto Insert Deposition Rate = (Machine variable)/SEC_PER_HR

Unload Time = (Machine variable)

User Inputs -- PCBA PTH Auto Insert

N/A

PTH Component Setup

Category: Prep Processes > Kitting

Description: The PTH Component Setup process is part of the “kitting” operation where an operator collects all the component part numbers and respective quantities required to build the specific PCBA or suite of PCBAs. Each component is loaded into a kit box which may or may not be separated by operation. (See also: [SMT Component Setup](#).)

Major Cost Drivers -- PCBA PTH Component Setup

PTH Component Setup **Cycle Time** is a sum of the time to gather the component from the storage area (pick time), load into a batch box, and return the component to storage at the completion of the job.

Process Time = ((Pick Time + Stock Return Time)*Qty PTH Part Types)/Batch Size

Pick Time = (Machine variable)

Stock Return Time = (Machine variable)

User Inputs -- PCBA PTH Component Setup

N/A

PTH Hand Install

Category: Plated Through Hole

Description: The PTH Hand Install process covers the manual insertion of Plated Through Hole components onto the PCB, as opposed to [PTH Auto Insert](#)).

Major Cost Drivers -- PCBA PTH Hand Install

PTH Hand Install **Cycle Time** is time it takes an operator to manually place a component on the PCB.

Process Time = Hand Place Time

**Hand Place Time = Qty of Hand Place Components/Hand Placement
Deposition Rate**

// Rate of PTH component deposition onto PCB

Hand Placement Deposition Rate = (Machine variable)/SEC_PER_HR

User Inputs -- PCBA PTH Hand Install

N/A

PTH Hand Solder**Category: Plated Through Hole**

Description: The PTH Hand Solder process involves a skilled operator using a soldering iron to make circuit connections. This is typically used only for rework or for very small production quantities. Hand soldering is sometimes used following wave soldering to add delicate components that would be damaged in the harsh environment of the wave soldering chamber.

Process is optional and is turned OFF by default.

Major Cost Drivers -- PCBA PTH Hand Solder

PTH Hand Solder **Cycle Time** is a product of the number of the leads by the rate of hand soldering.

Process Time = (Hand Solder PTH Leads Quantity)*(Hand Solder PTH Leads Time)

Hand Solder PTH Leads Quantity = (PSO)

Hand Solder PTH Leads Time = (Machine variable)

User Inputs -- PCBA PTH Hand Solder

PSO: Hand Solder PTH Leads Quantity

Reflow**Category: Surface Mount**

Description: Reflow is a Surface Mount (SMT) process in which components are held in place with solder paste while the PCB is heated to melt the solder to form the attachment between leads and pads. The heating process is typically divided into stages: preheat, soak, reflow, and cooling.

Major Cost Drivers -- PCBA Reflow

Process Time = Reflow Time + Unload Time

// Time to move through reflow oven.

Reflow Time = Reflow Oven Length/Reflow Oven Speed

Reflow Oven Length = (Machine variable)

Reflow Oven Speed = (Machine variable)

Unload Time = Output Conveyor Length/Output Conveyor Speed

Output Conveyor Length = (Machine variable)

Output Conveyor Speed = (Machine variable)

User Inputs -- PCBA Reflow

Process specific: N/A

Global Inputs: PCB Length, PCB Width, PCB Thickness, PCB Weight

RF Test**Category: Testing**

Description: RF Test is a process to ensure that the PCB neither emits nor is susceptible to radio frequency waves that exceed specific limits. For RF immunity testing, the equipment is exposed to RF disturbances and fields with field strengths and frequency ranges representative of their in-operation environment. For RF emissions testing, the equipment, under normal operation, is monitored for RF disturbances and fields.

Major Cost Drivers -- PCBA RF Test

RF Test **Cycle Time** is determined by creating a factored unit hour from the planned test time and the first pass yield value. The planned time will not always be achieved therefore it is important to account for the instances during which the test must be performed again.

Process Time = RF Test Time*(RF Test Yield/100)

RF Test Time = (PSO)

RF Test Yield = (PSO)

Hard Tooling Cost = RF Test Equipment Cost

RF Test Equipment Cost

User Inputs -- PCBA RF Test

PSO: RF Test Time

PSO: RF Test Yield

PSO: RF Test Equipment Cost

Screen Printing

Category: Surface Mount > Solder Application

Description: The Screen Printing process deposits solder paste onto a PCB by means of a stencil with apertures for each pad to be soldered. As a squeegee moves over the stencil (screen), solder paste is pressed through the apertures to the lands on the circuit board. Screen Printing is one of two options for Solder Application, the other being Solder Jetting (see [Solder Jetting](#)). Screen Printing is much more common than Solder Jetting and so is ON by default.

Note: It is not recommended to screen print a PCBA with pockets requiring paste deposits. These must be solder jetted.

Major Cost Drivers -- PCBA Screen Printing

Screen Printing **Cycle Time** is a sum of the time to load the PCB into the machine from the input conveyor, move the PCB to the lock position in the machine and clamp it down, look at the fiducials on the PCB and the corresponding ones on the stencil, make a theta adjustment to the rails to compensate for the fiducial alignment, raise the PCB to the stencil, lower the squeegee to the stencil and swipe across the PCB width to deposit paste, slowly release the PCB from the stencil, lower the screen printer rail, unload the PCB from the screen printer and output rail, and clean the stencil in the screen printer machine.

Process Time = Load Time + Screen Printer Cycle Time + Fiducial Check Time + Squeegee Time + Unload Time + Clean Time

Load Time = Input Conveyor Length/Input Conveyor Speed

Input Conveyor Length = (Machine variable)

Input Conveyor Speed = (Machine variable)

// Screen printer cycle time is a machine specification. It includes all cycle time to screen print PCB except for fiducial, print & cleaning time. It captures load, raise, adjust theta time.

Screen Printer Cycle Time = (Machine variable)

// Time to look at alignment fiducials or apertures on both PCB and stencil for alignment purposes.

Fiducial Check Time = (Machine variable) * Fiducial Quantity

Fiducial Quantity = (Machine variable)

// Time to move squeegee across stencil, therefore depositing solder paste through stencil apertures onto PCB.

Squeegee Time = Snap On Time + PCB Width/Squeegee Speed + Snap Off Time

Snap On Time = Snap Gap/Squeegee Speed

Snap Gap = (Machine variable)

Squeegee Speed = (Machine variable)

PCB Width = (PSO)

Snap On Time = Snap Gap/Squeegee Speed

Unload Time = Output Conveyor Length/Output Conveyor Speed

Output Conveyor Length = (Machine variable)

Output Conveyor Speed = (Machine variable)

// Stencil cleaning time. Not necessarily performed every time.

Clean Time = (Stencil Clean Time * Stencil Clean Frequency)/Batch Size

Stencil Clean Time = (Stencil Length/Clean Speed)*Swipe Quantity

Stencil Length = (Machine variable)

Clean Speed = (Machine variable)

Swipe Quantity = (Machine variable)

Stencil Clean Frequency = Batch Size /Clean Frequency

Clean Frequency = (PSO)

User Inputs -- PCBA Screen Printing

PSO: Fiducial Quantity (Number of fiducials to be inspected to ensure proper alignment of PCB to stencil.)

PSO: Stencil Clean Frequency (Number of PCBs printed prior to stencil clean.)

Selective Solder

Category: Plated Through Hole

Description: Selective Solder is a process for handling PTH components or connectors that cannot be wave soldered: for example, PTH components that are surrounded by SMT components that have already completed reflow. Selective solder addresses only the leads that have been programmed, and is much faster than hand soldering.

Major Cost Drivers -- PCBA Selective Solder

Selective Solder **Cycle Time** is the time to load and unload divided by the number of panels, plus the time to move through the selective solder machine.

Process Time = ((Load Time + Unload Time)/Panelization Quantity) + Selective Solder Time

Load Time = Mask Time + Flux Time + Fixture Load Time

// Mask Time, Flux Time, Fixture Load Time are only calculated.

Mask Time = (Machine variable)

Flux Time = (Machine variable)

Fixture Load Time = (Machine variable)

// Unload from machine and fixture, cooling optional.

Unload Time = Selective Solder Unload Time + Fixture Unload Time

Selective Solder Unload Time = (Machine variable)

// Fixture Unload Time is only calculated if PSO Fixture Requirements = true

Fixture Unload Time = (Machine variable)

Selective Solder Time = (Selective Solder Length/Selective Solder Speed) + (Quantity of PTH Leads/Nozzle Speed)

Selective Solder Length = (Machine variable)

Selective Solder Speed = (Machine variable)

Nozzle Speed = (Machine variable)

User Inputs -- PCBA Selective Solder

PSO: Masking Requirements (Y/N)

PSO: Flux Requirements (Y/N)

PSO: Fixture Requirements (Y/N)

Shunt Assembly

Category: Special Processing

Description: Shunt Assembly is the process of installing and electrically connecting a shunt onto a PCBA. In electronics, a shunt is a device which allows electric current to pass around another point in the circuit by creating a low resistance path. The shunt is mechanically secured to the PCB with hardware, and electrically connected to the circuit with solder and jumper wires.

Process is optional and is turned OFF by default.

Major Cost Drivers -- PCBA Shunt Assembly

Shunt Assembly **Cycle Time** is a combination of mechanical assembly to install the shunt into place, and jumper wire assembly to install the wires onto the shunt, and solder time to solder them onto the PCB.

Process Time = Shunt Install Process Time + Wire Install Process Time

Shunt Install Process = (Shunt Align Time*Shunt Quantity) + Hardware Install Time

Shunt Align Time = (Machine variable)

Shunt Quantity = (PSO)

Hardware Install Time = Hardware Stackup Locations* Hardware Stackup Install Time

Hardware Stackup Locations =(PSO)

Hardware Stackup Install Time = (Machine variable)

//Jumper wire installation. Note one end will be soldered and the other end will be assembled in hardware stackup.

Wire Install Process Time = (Jumper Wire Cut Time + Jumper Wire Strip Time + Jumper Wire Solder Time)* Jumper Wire Quantity) + Jumper Wire Staking Time + Jumper Wire Curing Time

Jumper Wire Cut Time = (Machine variable)

Jumper Wire Strip Time = (Machine variable)

Jumper Wire Solder Time = (Machine variable)

Jumper Wire Quantity = (PSO)

Jumper Wire Curing Time = Load Time + ovenTime

Load Time = Oven Load Time + Oven Unload Time

Oven Load Time = (Machine variable)

Oven Unload Time = (Machine variable)

Oven Time = (Machine variable) *SEC_PER_HR

//Jumper Wire Staking Time is only calculated if PSO Jumper Wire Staking Required = true

Jumper Wire Staking Time = { (Staking Mix Time/Batch Size) + (Jumper Wire Staking Time* Jumper Wire Staking Locations)

Staking Mix Time = (Machine variable)

Jumper Wire Staking Locations = (PSO)

User Inputs -- PCBA Shunt Assembly

PSO: Shunt Quantity

PSO: Hardware Stackup Locations

PSO: Jumper Wire Quantity

PSO: Jumper Wire Staking Required

PSO: Jumper Wire Staking Locations

SMT Auto Placement

Category: Surface Mount

Description: SMT Auto Placement is the process of installing Surface Mount (SMT) components on the surface of the PCB by machine. (See also: SMT Hand Placement)

Major Cost Drivers -- PCBA SMT Auto Placement

The Device Placement Time shown below is somewhat oversimplified. The cost model takes into account whether this is the top side or bottom side of the board, as well as different categories of components and their specific deposition rates.

Process Time = Travel Time + Load Time + Fiducial Check Time + Device Placement Time + Unload Time

Travel Time = Shuttle Conveyor Time + Transport Conveyor Time

Shuttle Conveyor Time = Shuttle Conveyor Length/Shuttle Conveyor Speed

Shuttle Conveyor Length = (Machine variable)

Shuttle Conveyor Speed = (Machine variable)

Transport Conveyor Time = (Transport Conveyor Length/ Transport Conveyor Speed)* Transport Conveyor Quantity

Transport Conveyor Length = (Machine variable)

Transport Conveyor Speed = (Machine variable)

Transport Conveyor Quantity = (Machine variable)

Load Time = Machine Load Time*Machine Quantity

Machine Load Time = (Machine variable)

Machine Quantity = (Machine variable)

Fiducial Check Time =(Machine variable)*Machine Quantity

Device Placement Time = Quantity Component Type/Component Type Disposition Rate

Unload Time = (Machine variable)*Machine Quantity

User Inputs -- PCBA SMT Auto Placement

PSO: Fixture Requirements override. (Adds fixture load / unload time to Machine Load / Unload time if true.)

SMT Component Setup

Category: Prep Processes > Kitting

Description: The SMT Component Setup process is part of the “kitting” operation where an operator collects all the component part numbers and respective quantities required to build the specific PCBA or suite of PCBAs. Each component is loaded into either a tape & reel or tray feeder. (See also: [PTH Component Setup](#))

Major Cost Drivers -- PCBA SMT Component Setup

SMT Component Setup **Cycle Time** is a sum of the time to gather the component from the storage area (pick time), load onto the required feeder, and then unload and return the component to storage at the completion of the job.

Process Time = ((Pick Time + Feeder Load Time + Feeder Unload Time + Stock Return Time)*Quantity of SM Part Types)/Batch Size

Pick Time = (Machine variable)

Feeder Load Time = (Machine variable)

Feeder Unload Time = (Machine variable)

Stock Return Time = (Machine variable)

User Inputs -- PCBA SMT Component Setup

Process Specific: N/A

SMT Hand Placement

Category: Prep Processes Surface Mount Plated Through Hole Special Processing Testing

Description: SMT Hand Placement is the process of having a worker install Surface Mount (SMT) components on the surface of the PCB manually. (See also: SMT Auto Placement). Machine selection provides the choice of three options: Unskilled, average, and highly skilled labor, differing in the number of parts per hour they can place. Default = "average".

Major Cost Drivers -- PCBA SMT Hand Placement

SMT Hand Placement cycle time is mainly determined by Hand Placement Deposition Rate.

Process Time = Device Placement Time

Device Placement Time = Quantity SM Hand Placed Components/Hand Placement Deposition Rate

Hand Placement Deposition Rate = (Machine variable) /SEC_PER_HR

// Throughput calculations for units per hour through this process.

Process Throughput = Process Capacity/(Cycle Time/SEC_PER_HR)

Process Capacity =(Machine Variable)

User Inputs -- PCBA SMT Hand Placement

SMT Hand Solder

Category: Surface Mount

Description: The SMT Hand Solder process involves a skilled operator using a soldering iron to make circuit connections. This is typically used only for rework or for very small production quantities. Machine choice provides for Unskilled, Average, and Highly Skilled operators, differing in Hand Solder SMT Leads Time (default = "Average").

Major Cost Drivers -- PCBA SMT Hand Solder

SMT Hand Solder **Cycle Time** is a product of the number of the leads by the rate of hand soldering.

Process Time = Hand Solder SMT Leads Quantity*Hand Solder SMT Leads Time

Hand Solder SMT Leads Quantity = (PSO)

Hand Solder SMT Leads Time (Machine Variable)

User Inputs -- PCBA SMT Hand Solder

PSO: Hand Solder SMT Leads Quantity

SMT Visual Inspection

Category: Surface Mount

Description: The SMT Visual Inspection process validates the minimum requirements for the PCBA. Unlike [Visual Inspection](#) for Plated Through Hole (PTH) PCBAs which occurs after soldering, SMT Visual Inspection takes place prior to solder reflow when the solder paste is soft and allows for components to be corrected by the visual inspection operator.

Major Cost Drivers -- PCBA SMT Visual Inspection

SMT Visual Inspection **Cycle Time** is the sum the time required to perform the visual inspection of the PCB prior to reflow and the transport time of the PCB along the In-Line Workstation. The visual inspection time is currently set as a machine variable of 30 seconds. This may be altered later based on customer's specification, but this is a good average time for the inspection of an average PCB prior to insertion in reflow oven.

Process Time = Visual Inspection Time + Transport Time

Visual Inspection Time =(Machine variable)

Transport Time = Visual Inspection Conveyor Length/ Visual Inspection Conveyor Speed

Visual Inspection Conveyor Length = (Machine variable)

Visual Inspection Conveyor Speed = (Machine variable)

User Inputs -- PCBA SMT Visual Inspection

PSO: Fiducial Quantity

PSO: Clean Frequency

Global Inputs: PCB Length, PCB Width, PCB Thickness & Pocket Existence Check

Software Load

Category: Special Processes

Description: The Component Software Load process loads firmware onto individual electronic components on the assembled board. The default software load machine is one computer with multiple connectors to program multiple different devices through those different connector locations.

Major Cost Drivers -- PCBA Software Load

Software Load **Cycle Time** is the time it takes to install the labels that identify the new part, plug the connector(s) required into the PCBA, and run the software load program.

Process Time = ((Label Print Time*Software Revision Label Quantity)/Batch Size) + (Label Install Time*Software Revision Label Quantity) + (Connector Mate Time *Connector Quantity) + Software Load Time

Label Print Time = (Machine variable)

Label Install Time = (Machine variable)

Software Revision Label Quantity = (PSO)

Connector Mate Time = (Machine variable)

Connector Quantity = (PSO)

Software Load Time = (PSO)

User Inputs -- PCBA Component Software Load

PSO: Label Quantity

PSO: Connector Quantity

PSO: Software Load Time.

Solder Jetting

Category: Surface Mount > Solder Application

Description: The Solder Jetting process deposits solder paste onto a PCB in the form of dots or lines, via a nozzle. Solder Jetting is one of two options for Solder Application, the other being Screen Printing which is the default (see [Screen Printing](#)). Solder Jetting is much less common so is off by default.

Major Cost Drivers -- PCBA Solder Jetting

Solder Jetting **Cycle Time** is a sum of the time to load the Printed Circuit Board (PCB) into the machine from the input conveyor, move the PCB to the lock position in the machine and clamp it down, look at the fiducials on the PCB, purge the solder paste from the nozzle and calibrate if required, deposit paste dots onto the PCB, and unload the PCB from the solder jetter and output rail.

Process Time = Load Time + Purge Time + Jet Time + Unload Time

Load Time = Input Conveyor Length/Input Conveyor Speed + Inside Conveyor Length/Inside Conveyor Speed + Clamp Time + Fiducial Check Time*3

Input Conveyor Length = (Machine variable)

Input Conveyor Speed = (Machine variable)

Inside Conveyor Length = (Machine variable)

Inside Conveyor Speed = (Machine variable)

Clamp Time = (Machine variable)

Fiducial Check Time = (Machine variable)

//A solder purge is required before solder jetting each PWB.

Purge Time = (Machine variable)

Jet Time = Dot Count / Jet Speed

Jet Speed = (Machine variable) / SEC_PER_HR

Dot Count = (PSO)

Unload Time = Output Conveyor Length/Output Conveyor Speed

Output Conveyor Length = (Machine variable)

Output Conveyor Speed = (Machine variable)

User Inputs -- PCBA Solder Jetting

PSO: Dot Count

Global Inputs: PCB Length, PCB Width, PCB Thickness, Pocket Existence Check

Solder Paste Inspection

Category: Surface Mount

Description: The Solder Paste Inspection (SPI) process measures the volume of the solder pads before the components are applied and the solder melted, to help reduce the incidence of solder-related defects.

Major Cost Drivers -- PCBA Solder Paste Inspection

Solder Paste Inspection **Cycle Time** is a sum of the time to load the PCBA into the machine from the input conveyor, move the PCB to the lock position in the machine and clamp it down, look at the fiducials on the PCB, move the inspection laser across the PCB, and unload the PCB from the machine and output rail..

Process Time = Load Time + Fiducial Check Time + Solder Paste Inspection Time + Unload Time

// Load into Machine. Input Conveyor time captured by Screen Printing Output Conveyor.

Load Time = (Machine variable)

Machine Load Time = (Machine variable)

// Time to look at alignment fiducials.

Fiducial Check Time = (Machine variable)

// Time to move laser across PCB and take measurements for SPI.

Solder Paste Inspection Time = PCB Area/Scanning Speed

PCB Area = PCB Width * PCB Length

PCB Width = (Global Input)

PCB Length = (Global Input)

Scanning Speed = (Machine variable)

// Unload and Conveyor after Solder Paste Inspection.

Unload Time = Output Conveyor Length/Output Conveyor Speed + Machine Unload Time

Output Conveyor Length = (Machine variable)

Output Conveyor Speed = (Machine variable)

Machine Unload Time = (Machine variable)

User Inputs -- PCBA Solder Paste Inspection

None process-specific.

Global Inputs: PCB Width, PCB Length

Stencil

Category: Prep Processes > PCB Prep

Description: The Stencil process applies information to the PCBA such as Part Number, Serial Number, Date Code, ESD Marking, and "Bad Board" Marking, etc. by painting a stencil onto the PCB. (See also: [Label](#))

Major Cost Drivers -- PCBA Stencil

Stencil **Cycle Time** is the time to make the stencil, aggregated across the batch size and the time to apply the individual stencils to each PCB.

Process Time = (Make Stencil Time/Batch Size) + (Stencil Time*Stencil Quantity)

Make Stencil Time = (Machine variable)

Stencil Time = (Machine variable)

Stencil Quantity = (PSO)

User Inputs -- PCBA Stencil

PSO: Number of stencil locations per individual PCBA.

Visual Inspection

Category: Plated Through Hole

Description: The Visual Inspection process is used for Plated Through Hole (PTH) PCBAs to validate the minimum requirements for the PCBA. Unlike [User Inputs -- PCBA SMT Hand Solder](#)

PSO: Hand Solder SMT Leads Quantity

SMT Visual Inspection which occurs before reflow soldering, Visual Inspection takes place after soldering operations have been completed.

Major Cost Drivers -- PCBA Visual Inspection

The process time for SMT Visual Inspection is the sum the time required to perform the visual inspection of the PCB prior to reflow and the transport time of the PCB along the In-Line Workstation. The visual inspection time is currently set as a machine variable of 30 seconds. This may be altered, but is a good average time for the inspection of an average PCB prior to insertion in reflow oven.

Process Time = Visual Inspection Time + Transport Time

Visual Inspection time = (Machine variable)

Transport Time = Visual Inspection Conveyor Length/Visual Inspection Conveyor Speed

Visual Inspection Conveyor Length = (Machine variable)

Visual Inspection Conveyor Speed = (Machine variable)

User Inputs -- PCBA Visual Inspection

N/A.

Wave Solder

Category: Plated Through Hole

Description: Wave Solder is the process for bulk soldering Plated Through Hole (PTH) printed circuit boards, by passing them over a pan of molten solder in which a pump produces an upwelling of solder that looks like a standing wave.

(For Surface Mount PCAs, see [Reflow.](#))

Major Cost Drivers -- PCBA Wave Solder

Cycle Time = Process Length / Conveyor Speed

Process Length = (Machine variable)

Conveyor Speed = (Machine variable)

User Inputs -- PCBA Wave Solder

PSO: Is masking required? (Default = True)

PSO Is flux required? (Default = True)

PSO: Is fixture required? (Default = True)

Process Defaults and Thresholds

Plant variables control several aspects of PCBA costing. Any PCBA entry can be adjusted as necessary for your local installation. Follow these steps to access plant variables for a given VPE and process:

- 3 Select **Tools > VPE Toolset**, and then click the **VPE Manager** button in the VPE Toolset window.
- 4 Double click the **PCB Assembly VPE** in the **Select VPE** window.
- 5 In the **VPE Manager**, click + to expand the **Assembly** and **User Guided** process groups.
- 6 Under these groups, click **Variables**.
- 7 Review the adjustment factor variables in the User Guided Process Group:
 - cycleTimeAdjustmentFactor
 - laborRateAdjustmentFactor
 - overheadRateAdjustmentFactor
 - purchaseVariance
- 8 Many PCBA variables are available in the Assembly Process Group, and are well documented in the comments columns. The following table lists these PCBA variables as of this writing. Use the procedure above to list the most up-to-date variables. The values in this table have been compiled from various industrial sources or from time studies in industrial applications, to provide reasonable defaults. You can adjust them if necessary to reflect your specific installation.

<i>Variable Name</i>	<i>String Value</i>	<i>Unit Type Name</i>	<i>Notes</i>
connectorQuantity	1		Quantity of connectors to be mated for software load.
cycleTimeAdjustmentFactor	1		Factor used to globally increase or decrease cycle time evaluations per process.
monitorPercentage	25		Default percentage of time the operator monitors full immersion Ion Chromatography.
numAutoPreformedParts	0		Quantity of different part types to be auto preformed. Used to determine how many times the batch setup must be performed per PCB Assembly.
panelizationHorizontalBuffer	5	Length	Distance between PCBs in Panel.
panelizationVerticalBuffer	5	Length	Distance between PCBs in Panel.
reflowBuffer	150	Length	Distance between PCBs required in Reflow process.

softwareLoad Time	90	Time	Time to load software onto component.
softwareRevisionLabelQuantity	1		Software Revision Label Quantity for each component to have software loaded.
solderPasteCost	150	Currency	Cost of a tube of solder used for Solder Printing and Solder Jetting in PCB Assembly.
stencilQuantity	2		Quantity of stencils per PCB that need to be applied.



aPriori Technologies, Inc.

300 Baker Avenue

Concord, MA 01742

www.apriori.com