

Pricing Additive Manufacturing Processes

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In the previous edition of TCT magazine I introduced Asiga QuoteServer, an online quoting and ordering tool for additive manufacturing businesses. Since then I've received many responses like: "Great, but, er, how exactly do I price my processes?" Surprisingly, a lot of bureaus use guesstimates to price their parts. This is damaging in the long run because underestimating hurts your profitability, while overestimating reduces your competitiveness.

I've devoted this article to being a tutorial on how to quote additive manufacturing processes correctly. You can easily adapt the examples given here to any additive process, such as stereolithography (SLA), multi-jet modelling (MJM), fused deposition modelling (FDM), selective laser sintering (SLS), digital light processing (DLP) and more. I'll also explain why most businesses fall into guesstimation methods instead of correct pricing models and how to easily break out of this habit.

Raster or Vector?

The first step is to identify what sort of process your additive manufacturing system uses. Processes generally fall under two categories: vector or raster based. Different pricing models apply to each.

Vector processes utilize a single processing point, such as a laser spot or an extrusion head, which is steered across a layer to fabricate the part. Generally, the time to produce each layer is a function of the area of the layer. Producing ten parts in parallel with a vector process takes approximately ten times as long as a single part. Examples of vector processes include selective laser sintering, laser stereolithography and fused deposition modelling.

Raster processes utilize multiple processing points to fabricate voxels of the part in parallel. For example, the processing device may be an arrayed printhead with multiple inkjet nozzles, or a multimedia projector which projects an array of pixels. With raster processes, the time to produce a layer of the part is independent of the cross-sectional area of the part. It generally takes the same time to produce one or ten parts in parallel, provided they fit into the system's build envelope. Examples of raster processes include DLP stereolithography and multi-jet 3D printing.

Which parameters do I need?

To calculate the cost of producing a part you need to start with the necessary parameters. Some parameters relate to the part geometry and others relate to the additive process being used.

Part Parameters. These can be calculated from the part's CAD data. The essential ones include: the part's volume, the part's shadow volume (i.e. the volume which needs to be supported), the part's bounding-box extents in the X, Y and Z directions, and the part's surface area.

Process Parameters. These are specific to the type of additive process being used. They include laser spot size and spot velocity (for stereolithography processes), time per layer (for raster processes), layer thickness, machine cost, and material costs.

Let's demonstrate with a couple of examples.

TABLE 1: Vector Process Pricing Model		Value	Units
Machine Cost and Utilisation:	Target income per year	500000	\$
	Operating days per year	250	days
	Operating hours per day	12	hours
	>>> Cost Per Hour	166.6667	\$/hour
Machine Attributes:	Scan Velocity mm/s	3000	mm/s
	Spot Size	0.125	mm
	Layer thickness	0.1	mm
	Time per layer levelling	5	s
	Build Envelope X	250	mm
	Build Envelope Y	250	mm
	Build Envelope Z	250	mm
	Z Null Height	4	mm
Part Attributes:	Part X	100	mm
	Part Y	50	mm
	Part Z (height)	50	mm
	Part Volume	20000	mm ³
	Part Shadow Volume	7000	mm ³
	>>> Number of layers	540	
	>>> Scanning Time	533.3333	s
	>>> Levelling Time	2700	s
	>>> Total Build Time	3233.333	s
	>>> Machine Time Cost	149.6914	\$
Material:	Build material cost	0.5	\$/cm ³
	>>> Material cost	10.35	\$
TOTAL	>>> Total Cost	160.04	\$

Example 1: A Vector Process – Laser Stereolithography

Table 1 summarises the key variables used in pricing a laser stereolithography process. Blue squares indicate required input process parameters. Yellow squares indicate parameters calculated by geometric analysis of the CAD file (e.g. in STL or SLC format). Green squares indicate computed values.

The first section of Table 1 calculates the cost of the equipment per unit time. The calculation is:

$$\text{Cost_per_hour} = \text{Target_Income_Per_Year} / (\text{Operating_days_per_year} * \text{Operating_hours_per_day})$$

Notice that I've used "target income per year" as the primary cost in the numerator, not simply "machine cost per year". If you're running a business then the cost of staff salaries and keeping the lights on in your facility may dominate the costs of finance and machine servicing.

The second section of Table 1 contains the key attributes of the particular stereolithography machine in question. For example, the “time per layer levelling” is the time it takes for the wiper blade to transit from one side of the vat to the other. The “Z Null Height” is height of support structures which must be laid down before the actual part’s layers start printing.

The third section of Table 1 contains part attributes that are determined from geometric analysis of the STL or SLC file. These include X, Y and Z extents of the parts bounding box, part volume and shadow volume.

The fourth section of Table 1 contains the calculations leading to the final result. Let’s work through them. Note that for simplicity I’ve omitted any unit conversions from the equations.

$$\text{Number_of_layers} = \text{Part_Z} / (\text{Layer_Thickness} + \text{Z_Null_Height})$$

$$\text{Scanning_Time} = \text{Part_Volume} / (\text{Layer_Thickness} * \text{Spot_Size} * \text{Scan_Velocity})$$

$$\text{Levelling_Time} = \text{Number_of_layers} * \text{Time_per_layer_levelling}$$

$$\text{Total_Build_Time} = \text{Scanning_Time} + \text{Levelling_Time}$$

$$\text{Machine_Time_Cost} = \text{Build_Time} * \text{Cost_Per_Hour}$$

Material costs comprise that used for the part and also the support structures. Here I’ve assumed that the support volume is 10% of the part’s shadow volume.

$$\text{Material_Cost} = \text{Build_Material_Cost} * \text{Part_Volume} + \text{Build_Material_Cost} * \text{Shadow_Volume} * 0.1$$

The total cost is then:

$$\text{Total_Cost} = \text{Machine_Time_Cost} + \text{Material Cost}$$

TABLE 2: Raster Process Pricing Model		Value	Units
Machine Cost and Operation:	Target income per year	350000	\$
	Operating days per year	250	days
	Operating hours per day	12	hours
	>>> Cost Per Hour	116.67	\$/hour
Machine Attributes:	Seconds per layer	20	s
	Layer thickness	0.016	mm
	Build Envelope X	127	mm
	Build Envelope Y	178	mm
	Build Envelope Z	230	mm
	Z base height	4	mm
	>>> Cost Per Hour Per mm² of XY Area	0.00516	\$/hour/mm²
Part Attributes:	Part X	25	mm
	Part Y	25	mm
	Part Z (height)	25	mm
	Part Volume	5000	mm ³
	Shadow Volume	2000	mm ³
	>>> Number of layers	1812.5	
	>>> Build Time	10.069	hours
	>>> Fraction of Build Envelope	0.028	
>>> Machine Time Cost	32.47944	\$	
Material Cost:	Build material cost \$/cm ³	0.50	\$/cm ³
	Support material cost \$/cm ³	0.20	\$/cm ³
	>>> Material cost	2.90	\$
TOTAL	>>> Total Cost	35.38	\$

Example 2: A Raster Process – Multi-Jet Modelling

Table 2 summarises the key variables used in pricing a raster process. The example here is based on a multi-jet 3D printer which utilizes a sacrificial support material. The calculation has many similarities to the vector process of Example 1, except that we need to consider that multiple parts in the build envelope build simultaneously without incurring any additional cost in machine time. For this reason we calculate a machine cost per hour per unit area:

$$\text{Cost_Per_Hour_Per_XY_Area} = \text{Cost_Per_Hour} / (\text{Build_Envelope_X} * \text{Build_Envelope_Y})$$

where the Cost_Per_Hour is calculated as described previously for a vector process.

We also have a constant printing time per layer to consider. Each layer is printed in a known number of passes of the print head. Working through the calculations:

$$\text{Build_Time} = \text{Number_of_layers} * \text{Time_per_layer}$$

$$\text{Fraction_of_Build_Envelope} = \text{Part_X} * \text{Part_Y} / (\text{Build_Envelope_X} * \text{Build_Envelope_Y})$$

$$\text{Machine_Time_Cost} = \text{Build_Time} * \text{Cost_Per_Hour_Per_XY_Area} * \text{Part_X} * \text{Part_Y}$$

The material costs are calculated as follows:

$$\text{Build_Material_Cost} = \text{Part_Volume} * \text{Build_Material_Cost}$$
$$\text{Support_Material_Cost} = \text{Shadow_Volume} * \text{Support_Material_Cost}$$

The total cost is then the sum of the machine time cost, build material cost and support material cost, i.e.

$$\text{Total_Cost} = \text{Machine_Time_Cost} + \text{Build_Material_Cost} + \text{Support_Material_Cost}$$

That was easy, right?

The calculations are easy once you have the correct parameters. And there lies the problem: While many STL file viewers can give you the part's volume and bounding box extents, there's no CAD program that I'm aware of that gives you the part's shadow volume easily. And even if there was, isn't it a little backwards to be manually processing parts and entering values into spreadsheets when computers are designed to do that for you?

A solution

We developed Asiga QuoteServer with the above issues in mind. We realised additive manufacturing businesses needed a simple platform to automate quoting, ordering and production management. All the necessary part parameters are calculated automatically, and there are numerous templates for pricing raster and vector processes like those presented above and plenty more. QuoteServer is a completely web-based tool that can be configured and branded to your business in a matter of hours. QuoteServer gives a bureau the scalability and online presence of the world's biggest prototyping bureaus with zero up-front investment.

Conclusion

Incorrect quoting damages your business in the long run by losing money or losing customers to the competition. Additive manufacturing businesses may struggle to implement exact pricing models because the necessary parameters require specific analysis of CAD files which isn't readily available. Asiga QuoteServer is designed to automate online quoting and ordering specifically for additive manufacturing businesses. Asiga QuoteServer has no up-front costs and will make your business more profitable. More can be learned at www.quoteserver.com or www.asiga.com.