Cost-Benefit Analyses

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Additive manufacturing (AM) has progressed to the stage where final production parts can be printed in a wide range of polymers and metals.

However, just because a part *can* be produced using AM does not necessarily mean that it *should* be. Prior to implementing the technology for a production application, it is essential to conduct a thorough cost-benefit analysis.

When trying to determine whether a particular part can be cost-effectively manufacturing by AM, it is critical to analyze the entire supply chain. Initially, the supply chain should be examined from a qualitative standpoint. Courtesy of Senvol, below are the seven supply chain scenarios that tend to lend themselves well to AM. If a part falls into one or more of these scenarios, it may be cost-effective to produce via AM and is a candidate for further evaluation. If a part does not fall into any of these scenarios, the part almost certainly will not be cost-effective for AM, given the current state of AM technology.

Scenario	Scenario Description
Expensive to Manufacture	Do you have parts that are high cost because they have complex geometries, high fixed costs (e.g. tooling), or are produced in low volumes? AM may be more cost-efficient.
Long Lead-Times	Does it take too long to obtain certain parts? Are your downtime costs extremely high? Do you want to increase speed-to-market? Through AM, you can often get parts more quickly.
High Inventory Costs	Do you overstock or understock? Do you struggle with long-tail or obsolete parts? AM can allow for on-demand production, thus reducing the need for inventory.
Sole-Sourced from Suppliers	Are any of your critical parts sole-sourced? This poses a supply chain risk. By qualifying a part for AM, you will no longer be completely reliant on your current supplier.
Remote Locations	Do you operate in remote locations where it is difficult, time consuming, or expensive to ship parts to? AM may allow you to manufacture certain parts on-site.
High Import / Export Costs	Do you pay substantial import/export costs on parts simply because of the location of your business unit and/or your supplier? On-site production via AM can eliminate these costs.
Improved Functionality	AM can enable a part to be redesigned such that its performance is improved beyond what was previously possible.

A detailed, quantitative cost-benefit analysis is warranted for any part that falls into one or more of the previous scenarios. To conduct such analyses, the Senvol Algorithm was developed to determine which types of parts can be manufactured more cost-effectively using AM versus the status quo. The algorithm analyzes an array of variables that span the entire product life cycle.

The following sections detail three analyses that Senvol has conducted. The first provides an example of a part that is cost-effective for AM. The second offers a part that is not cost-effective for AM. The third presents an example where cost-effectiveness for AM is dependent upon the quantity produced.

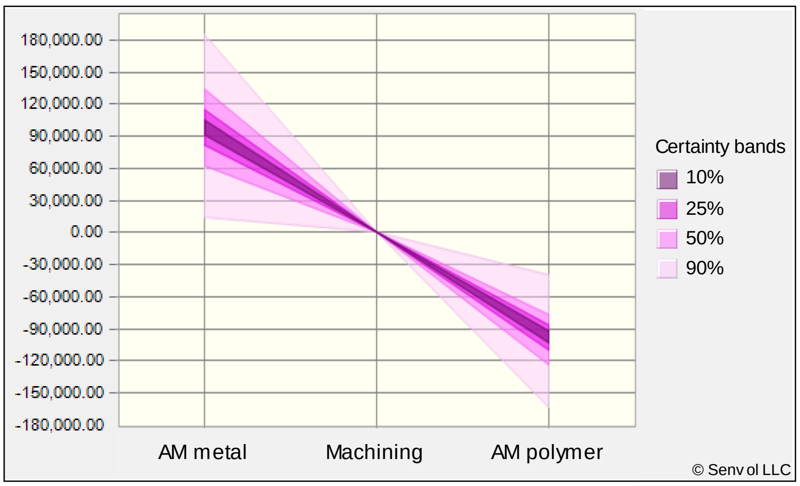
Cost-Effective Use Case

The part analyzed in this case was for the Measurement & Control division of General Electric (GE). The part measures 50 x 50 x 90 mm (2.0 x 2.0 x 3.5 inches) and is currently machined from an aluminum alloy. Most customers require a custom variation of the part. The batch size that each customer orders is highly variable, ranging from a few to several hundred. The part was redesigned for AM to achieve better functionality. Interestingly, all engineering specifications were able to be met by both an AM metal process as well as an AM polymer process. (Note: Further details about the part, including the specific AM materials analyzed, cannot be disclosed due to confidentiality).

Three production options were analyzed:

1. Machining (the status quo)
2. AM metal
3. AM polymer

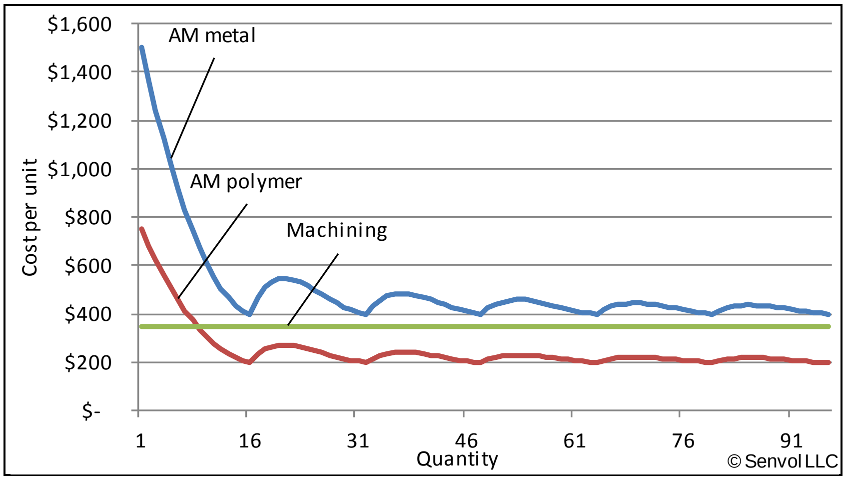
The total cumulative cost over 10 years (net present value of 2014–2023) was computed for the three production options. The total cumulative cost for machining was set to $0. The total cumulative cost for AM metal and AM polymer were then compared relative to machining. On average, over the 10-year period, producing the part via AM metal is approximately $99,051 *more* expensive than via machining, but producing the part via AM polymer is approximately $100,534 *less* expensive than via machining.



Comparison of AM metal and AM polymer total cumulative cost over 10 years (in 2013 U.S. dollars) relative to machining cost.

The Senvol Algorithm is based on Monte Carlo simulations to account for variability of the inputs. The previous graph shows that, with 90% certainty, AM metal would be $14,444–188,823 more expensive than machining and AM polymer would be $41,479–165,227 less expensive than machining over 10 years.

The graph below shows the cost per unit for the three production options as a function of the quantity of units produced.



The machining cost curve is flat and does not reflect economies of scale because GE had negotiated a fixed rate per part with its supplier. Normally, tool path generation and optimization, set-up time, and possible trials would be taken into account, which would cause the first few parts to be much more expensive. The "wave" pattern in the two AM cost curves is caused by inefficient build batches (i.e., batches that do not fill the entire build volume of the AM machine). Based on GE's order quantities—the majority of which were over 12 units—the use of AM polymer was the least expensive production option.

This part falls into the "Expensive to Manufacture" scenario in the seven supply chain scenarios described previously. Due to its complex geometry, it is difficult and therefore expensive to machine the part, whereas AM polymer can produce it more cost-effectively. By redesigning the part, it was possible to produce an AM polymer part that met the mechanical requirements of the original machined metal part, which led to significant cost savings.

Non Cost-Effective Use Case

The part analyzed in this case was for the automotive division of Johnson Controls, Inc. The part measures 250 x 120 x 50 mm (9.8 x 4.7 x 2.0 inches) and is currently injection molded in polypropylene. Approximately 8,500 units are sold each year. The part was redesigned for AM, and no finishing or post-processing was required. (Note: Further details about the part cannot be disclosed due to confidentiality).

Four production options were analyzed:

1. Injection molding (the status quo)
2. In-house production via one 3D Systems sPro 230 AM machine
3. In-house production via eight 3D Systems ProX 500 AM machines
4. Outsourcing to an AM service bureau

All three AM production options were considered with the 3D Systems DuraForm EX Black material.

The cost per unit for the four production options is shown in the following table, broken down by cost component.

Cost Component	Injection Molding	sPro 230	ProX 500	Service Bureau
Unit Purchase Price	$1.99			
New Tooling	$0.36			
Tooling Maintenance	$0.14			
Excess Operational Cost	$0.15			
Material Cost		$26.65	$26.65	
AM Annual Services Cost		$1.69	$12.68	
Redesign Cost		$0.01	$0.01	$0.01
AM Machine Cost		$9.42	$29.90	
Qualification Cost		$1.50	$11.25	
Labor Cost		$0.15	$2.89	
Service Bureau Unit Cost				$147.50
Service Bureau Shipping Cost				$0.84
Total Cost per Unit	**$2.64**	**$39.42**	**$83.38**	**$148.35**

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At $2.64 per unit, injection molding is substantially less expensive than any of the AM options. The sPro 230 is the most cost-effective AM option at $39.42 per unit.

Further analysis was conducted by the Senvol Algorithm to determine which sPro 230 AM variables would need to improve – and by what magnitude – in order for AM to *become* cost-effective. Each variable improvement was considered in isolation (i.e., holding all other variables constant). Below is a heat map showing the impact each variable improvement would have on cost per unit. The green cells show that the variable change has little impact on cost per unit, while the red cells show that the variable change had significant impact on cost per unit.

		Variable improvement level								
Variable	Current AM values	10%	20%	30%	40%	50%	60%	70%	80%	90%
Material cost ($/cu inch)	$2.50	$36.76	$34.09	$31.43	$28.76	$26.10	$23.43	$20.77	$18.10	$15.44
Unit part volume (cu inch)	8.2	$36.76	$34.09	$31.43	$28.76	$26.10	$23.43	$20.77	$18.10	$15.44
AM machine cost	$780,000	$38.48	$37.54	$36.59	$35.65	$34.71	$33.77	$32.82	$31.88	$30.94
# parts/batch	60	$38.26	$37.29	$36.47	$35.77	$35.16	$34.63	$34.16	$33.74	$33.37
Non-usable scrap rate	30%	$38.81	$38.19	$37.58	$36.96	$36.35	$35.73	$35.12	$34.50	$33.89
# hours to print full bed	20	$38.86	$38.29	$37.73	$37.17	$36.60	$36.04	$35.48	$34.91	$34.35
# hours to cure full bed print	20	$38.86	$38.29	$37.73	$37.17	$36.60	$36.04	$35.48	$34.91	$34.35
AM machine Life (years)	7	$38.56	$37.85	$37.25	$36.73	$36.28	$35.89	$35.54	$35.23	$34.96
AM annual services cost	$20,000	$39.25	$39.08	$38.91	$38.74	$38.57	$38.41	$38.24	$38.07	$37.90
Qualification cost/batch	90	$39.27	$39.12	$38.97	$38.82	$38.67	$38.52	$38.37	$38.22	$38.07
Machine downtime	10%	$39.30	$39.18	$39.06	$38.94	$38.83	$38.72	$38.61	$38.50	$38.40
Labor rate ($/hour)	$17.50	$39.40	$39.39	$39.37	$39.36	$39.34	$39.33	$39.31	$39.30	$39.28
# labor hours/week	2	$39.40	$39.39	$39.37	$39.36	$39.34	$39.33	$39.31	$39.30	$39.28
Redesign cost	$4,000	$39.42	$39.42	$39.42	$39.42	$39.42	$39.42	$39.42	$39.42	$39.42

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Example: The top left cell (circled in red) shows that if material cost improves by 10% (i.e. if it decreases from $2.50 to $2.25), then the total cost per unit (holding all other variables constant) drops to $36.76 (from $39.42).

As can be seen in the chart above, material cost, unit part volume (i.e. if the part can be redesigned to use less material), and AM machine cost are the three most impactful variables. However, no single variable – regardless of the improvement level – can make AM cost-effective compared to injection molding, which is only $2.64 per unit.

Consequently, this means that multiple AM variables would need to improve in order for AM to become cost-effective for this particular part.

To illustrate this point, a fictional scenario with improvements to multiple AM variables for the sPro 230 production option is shown in the following table. With all of the listed variables improving by the percentages shown, AM cost per unit drops from $39.42 to $2.63, which is one cent less than the $2.64 cost per unit by injection molding.

Variable	Current AM Values	Improvement	Improved AM Values
AM machine cost	$780,000	30%	$546,000
AM machine life (years)	7	50%	11
AM annual services cost	$20,000	90%	$2,000
Material price ($/cu inch)	$2.50	90%	$0.25
Non-usable scrap rate	30%	65%	11%
# parts/batch	60	300%	240
Unit part volume (cu inch)	8.2	10%	7.38
Labor rate ($/hour)	$17.50	0%	$17.50
# labor hours/week	2	50%	1
# hours to print full bed	20	50%	10
# hours to cure full bed print	20	50%	10
Qualification cost/batch	$90	90%	$9
Redesign cost	$4,000	0%	$4,000
Machine downtime	10%	50%	5%

Current injection molding cost/unit: **$2.64**
Current AM cost/unit: **$39.42** (using current AM values above)
Improved AM cost/unit: **$2.63** (using improved AM values above)

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The above table shows that, given substantial improvements, AM could become cost-effective compared to injection molding for parts such as this.

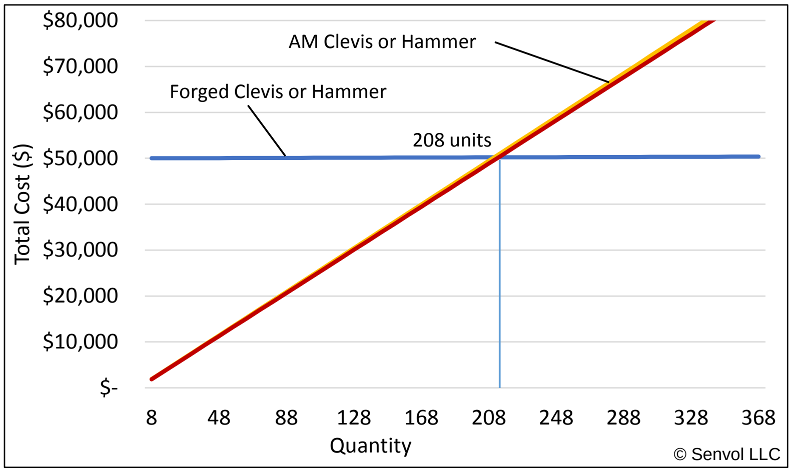
(Note: Energy cost was not calculated in this case and is an area that warrants further analysis).

Quantity-Dependent Use Case

Two different parts (a clevis and hammer) were analyzed in this case for the Forging Industry Association. The clevis is about 140 mm (5.5 inches) long and has a volume of 56 cm^3 (3.4 $inches^3$). The hammer about 180 mm (7 inches) long and has a volume of 47 cm^3 (2.85 $inches^3$). Both parts are currently produced in carbon steel by forging. The AM versions of the parts were produced on an EOSINT M 270 machine.

Clevis and hammer parts, courtesy of Green Bay Drop Forge

When an order for parts such as these is received, a key decision needs to be made. Should the parts be produced by forging, which requires tooling, or would it be more cost-effective to use AM? As the following graph indicates, AM is cost-effective for production quantities less than 208 units, whereas forging is cost-effective for quantities greater than 208 units.



Summary

Given current technology levels, some parts are cost-effective to produce by AM. Such parts typically fall into at least one of the seven supply chain scenarios that were previously outlined. In these cases, the amount of money saved from switching production to AM can be significant.

For parts that are not currently cost-effective for AM, no one variable can be singled out as the cause of AM's higher cost. That said, scenarios can be constructed to show which AM variables need to improve for a part to become cost-effective for AM. The AM variables with the greatest impact on total AM cost are often material cost, part volume, AM machine cost, and AM machine throughput.

Overall, when considering whether to implement AM, there is no substitute for conducting a cost-benefit analysis that evaluates the entire supply chain and product life cycle. Doing so may not only lead to substantial cost-savings today, but will also enable your firm to understand which AM metrics to track in the future. AM technology is advancing quickly, and so having a thorough understanding of when to implement the technology will enable your firm to gain a competitive advantage.