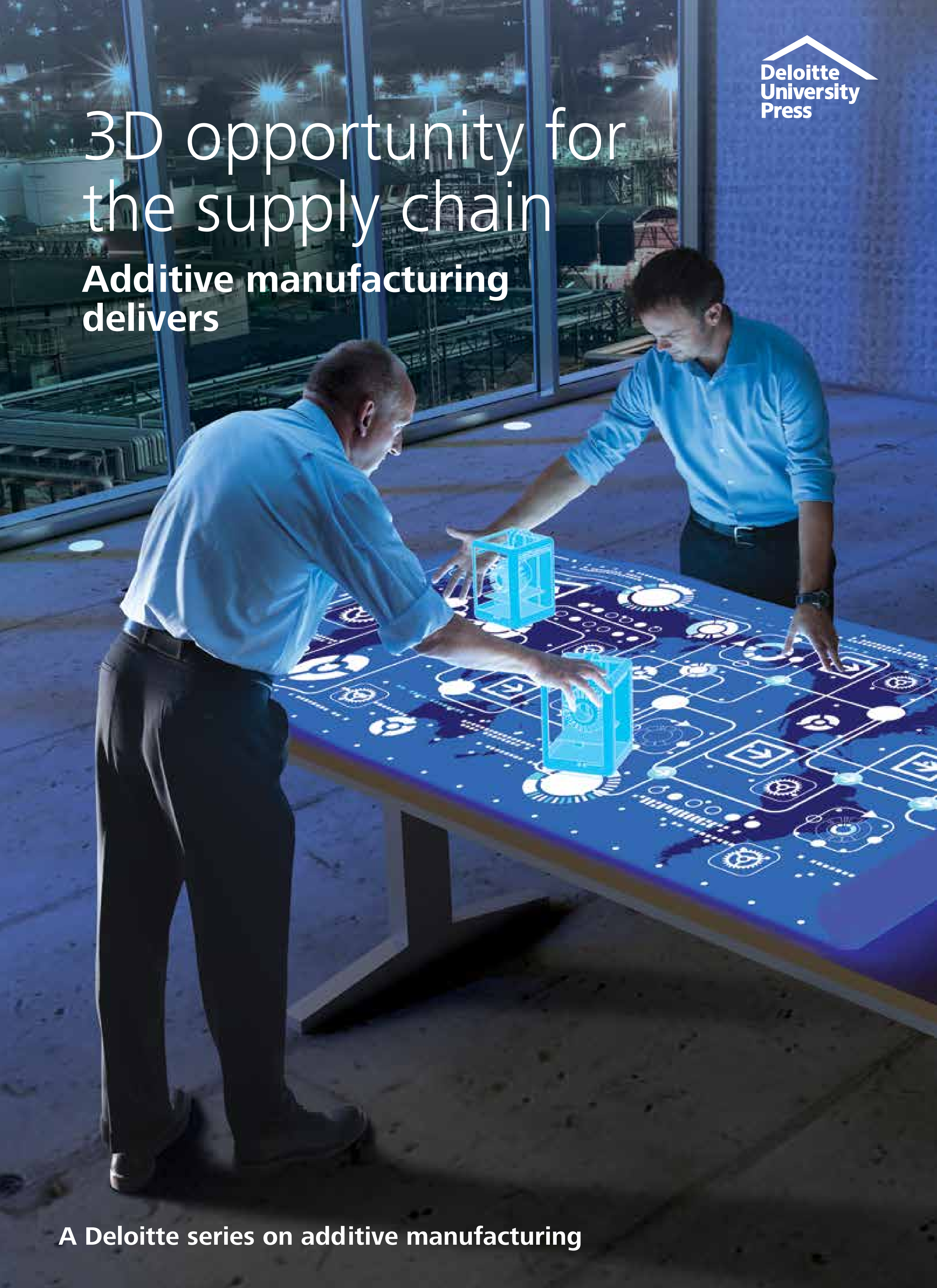
3D opportunity for the supply chain

Additive manufacturing delivers



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Deloitte Consulting LLP's supply chain and manufacturing operations practice helps companies understand and address opportunities to apply advanced manufacturing technologies to impact their businesses' performance, innovation, and growth. Our insights into additive manufacturing allow us to help organizations reassess their people, process, technology, and innovation strategies in light of this emerging set of technologies. Contact the authors for more information, or read more about our alliance with 3D Systems and our 3D Printing Discovery Center on www.deloitte.com.

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Introduction

EVEN the strongest supply chain has a few weak links. Maybe yours are concentrated upstream, with small manufacturers that suffer from quality-control issues, or downstream, with retailers that have trouble getting products into customers' hands on time. Either way, you may be able to bolster those links—or forge some alternatives—with the help of additive manufacturing.

In the last few years, additive manufacturing (commonly referred to as 3D printing) has moved far beyond its original prototyping applications to play an integral part in some companies' product lines and production approaches.[1] And, for many, its most useful role may turn out to be less in creating new products than in enhancing supply chain capabilities—or even innovating across whole sections of those supply chains.

Consider an industrial product manufacturer with a customer who needs a particular low-demand service part immediately, and can't wait for shipping from a central warehouse or, worse, for fabrication by some remote supplier. If a dealer could simply "print" a new component on the spot, that customer could be served far more efficiently and effectively.

Or think of what now happens when an obscure machine part breaks at a remotely located factory: While waiting for trains and trucks to deliver a replacement, operations leadership must devise workarounds or let the shop floor sit idle. An on-site 3D printer might fabricate a new part and enable barely a pause in productivity—potentially saving thousands or tens of thousands of dollars per hour in facility downtime.

AM is becoming increasingly valuable in helping organizations break existing performance tradeoffs...

Additive manufacturing (AM) became commercially viable in the mid-1980s and has recently expanded from prototyping to tooling and end-user part production.[2] AM has made an impact in many industries, including aerospace and defense,[3] automotive,[4] consumer products, industrial products, medical devices,[5] and architecture. With an overall market size for printers, materials, and printing services estimated at $4.1 billion in 2014,[6] AM is becoming increasingly valuable in helping organizations break existing performance tradeoffs in two fundamental ways: The technology reduces the capital required to achieve economies of scale, and it increases flexibility and reduces the capital required to achieve scope.

Changing the capital-versus-scale relationship—reducing the capital required to reach minimum efficient scale for production—can affect how companies configure supply chains. Changing the capital-versus-scope relationship—reducing the cost of expanding the product line—can affect product designs.[7]

These impacts present companies with choices on how to deploy AM across their businesses. Deloitte has identified four strategic paths that companies can take in adopting 3D printing in their products and/or supply chains, described in the article *3D opportunity: Additive manufacturing paths to performance, innovation, and growth*[8] and outlined in the framework illustrated in figure 1.

Path I: Companies do not seek radical alterations in either supply chains or products, but explore AM technologies to improve value delivery for current products within existing supply chains.

Path II: Companies take advantage of scale economics offered by AM as an enabler of supply chain transformation for the products they offer.

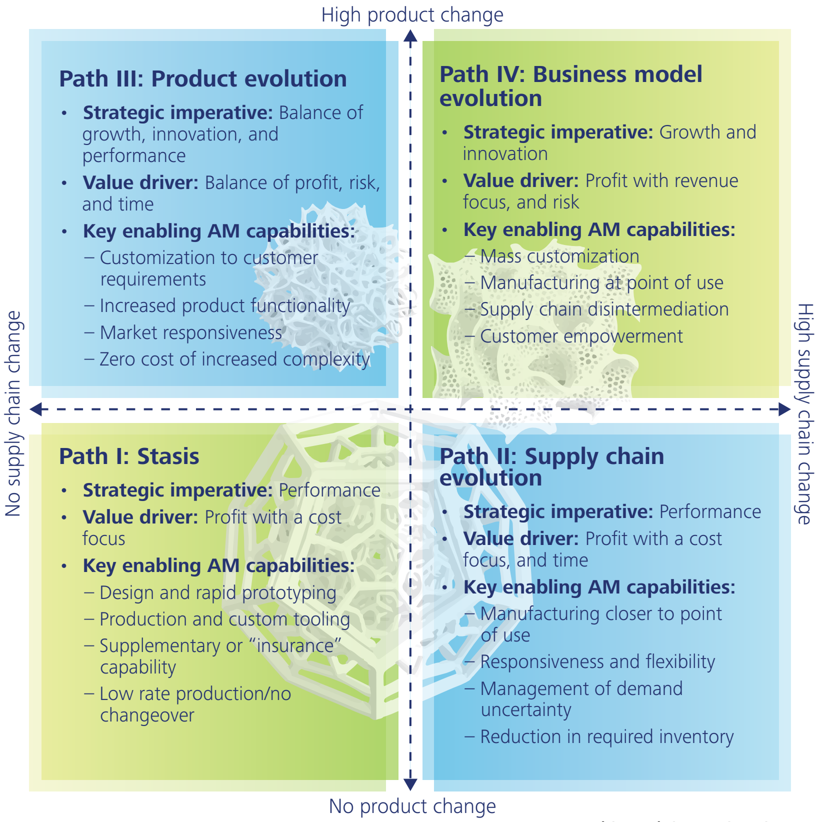
Path III: Companies take advantage of the scope economics offered by AM technologies to achieve new levels of performance or innovation in the products they offer.

Path IV: Companies alter both supply chains and products in the pursuit of completely new business models previously not possible without AM.

This article focuses on AM's supply chain impact—path II in our framework—showing ways in which organizations can use 3D printing to evolve their supply chains, whether or not they simultaneously alter their product offerings. Evidence and experience have shown that using these technologies to evolve supply chains can offer strong value and a competitive advantage for companies willing to invest in this way. Indeed, 24 percent of manufacturing firms are currently using AM in some form, a percentage that rises to 50 percent among supply chain leaders. A further 21 percent of manufacturing firms plan to use AM within the next three years.[9] This suggests a strong competitive advantage for those who can differentiate themselves through AM.

AM's impact on supply chains can take many forms, including reduced material waste, increased production flexibility, and the ability to decentralize production. Adopters can redesign everything from sourcing of materials to product distribution, rethinking the way they deliver products to end users. Eventually, companies may combine supply chain evolution

Figure 1. Framework for understanding AM paths and value

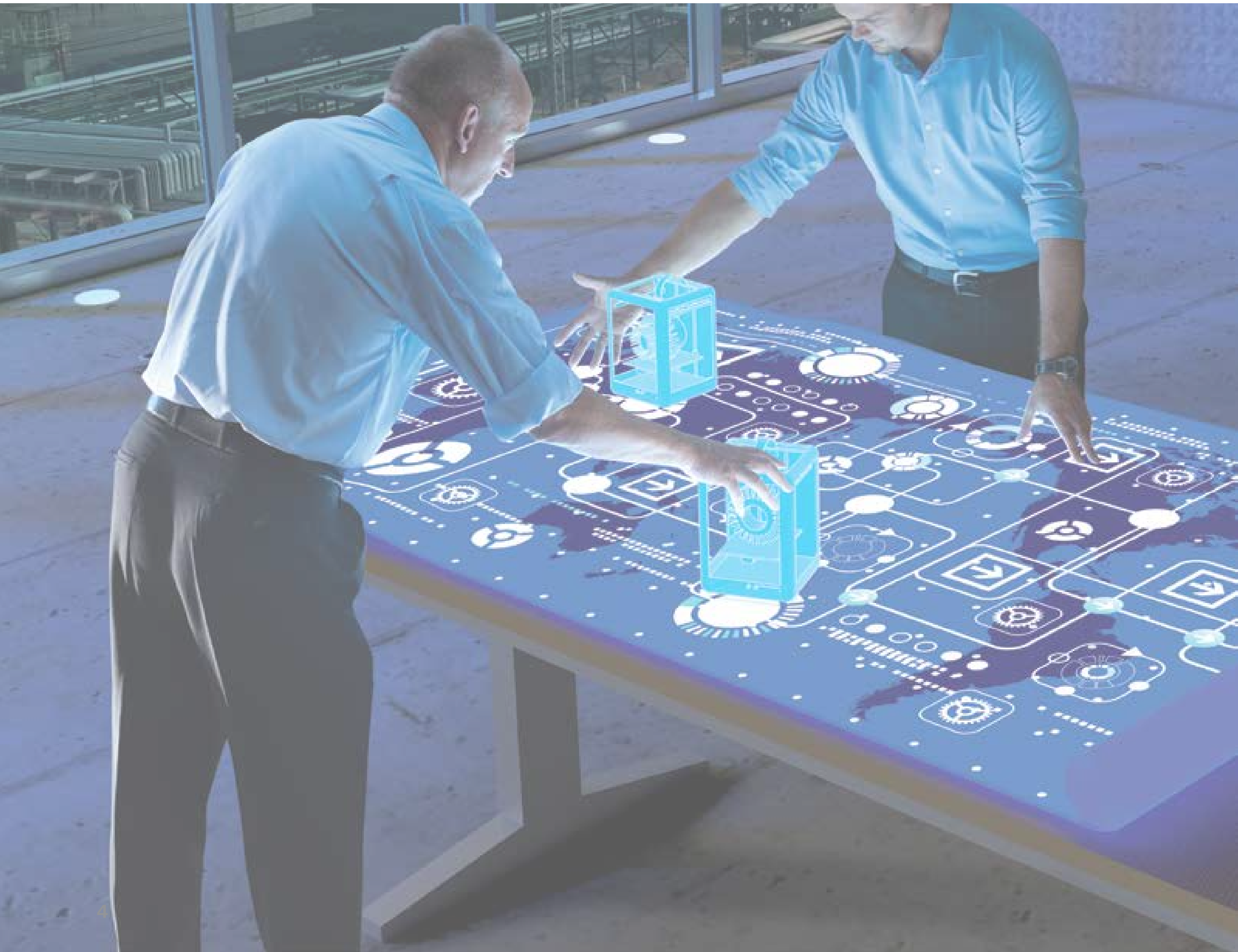


Graphic: Deloitte University Press | DUPress.com with product evolution to reach the path IV (business model evolution) quadrant.

Here, we use the research literature and other use cases to explore how companies are using AM to rethink their supply chains to improve performance in the following ways:

- Reduce material inputs for leaner manufacturing
- Simplify production processes, reducing costs
- Lower risk by providing a contingency plan
- Improve process flexibility, reacting faster to demand
- Redesign supply chain networks into decentralized, distributed production networks
- Reduce the capital cost of entry into new markets

The benefits described may exist on a spectrum (in some cases crossing over into path IV—business model evolution). The magnitude of disruption to an existing supply chain, however, depends on a given company's specific context and supply chain characteristics. In order to develop and/or adequately manage a longer-term strategic plan for AM deployment, it is important to consider the diversity of potential impacts and reimagine the supply chain's potential configuration.



Reducing material inputs for leaner manufacturing

AM technology offers manufacturers the ability to produce higher-performing designs than may be possible using traditional manufacturing techniques. In traditional processes, the level of material input required for production is closely tied to the product's design complexity. AM attenuates the tie between design complexity and material need, helping companies work toward leaner manufacturing while improving design quality.

Lockheed Martin recently demonstrated AM's ability to dramatically reduce the material inputs required for the production of aerospace components. Centering on components made of high-value materials such as titanium alloys, Lockheed's AM use has reduced the buy-to-fly ratio—the ratio of material inputs to final part output. One targeted part was a bleed air-leak detect (BALD) bracket, traditionally machined using subtractive manufacturing with a buy-to-fly ratio of 33:1, meaning that 33 pounds of raw stock metal is required to create a one-pound machined bracket. Lockheed has used AM to bring this ratio down to nearly 1:1, reducing bracket manufacturing costs by over 50 percent.[10]

One major aircraft manufacturer is conducting experiments focused on using AM to manufacture metal brackets requiring less material input than those produced using conventional techniques. Currently, the brackets are produced using computer numerical control (CNC) machining, which turns 80 to 90 percent of costly aerospace aluminum into scrap in the form of removed material. Using AM, the manufacturer is able to reduce the amount of material waste while simultaneously producing brackets that are 50 to 80 percent lighter than their CNC-machined counterparts.[11]

AM-based designs can integrate complex geometries such as honeycombed structures and lattices into traditional product designs, reducing both weight and the amount of material required to create a part. Medical manufacturers, for example, have applied designed surface porosity to promote bone-cell ingress to hip-replacement components—with some components having 60 percent less material than the original, traditionally manufactured geometry. These complex designs can help optimize product strength-to-weight ratios, reducing the amount of raw material required in the supply chain.[12]

Action items:

- Consider the various parts and products you manufacture to determine which may have geometries complex enough to warrant an examination of AM.

- Review the specific needs customers have regarding your parts (strength, porosity, and so on) to understand where parts may better meet those needs through an AM approach to production.

- Take an audit of the amount of raw material your current manufacturing methods consume (that is, buy-to-fly ratios) to determine if an AM approach may necessitate fewer materials.

- Take a closer look at parts that use highest-cost materials to determine where cost savings can be achieved.

Simplifying production processes, reducing costs

AM technology also enables some manufacturers to alter their production processes, simplifying supply chains by reducing the number of assembly steps that a product must undergo to reach its final form. AM does this by giving designers the ability to redesign parts to take advantage of part and sub-assembly consolidation. Parts and sub-assemblies machined as separate pieces can be manufactured as single objects using AM. This can have major impacts on the supply chain, including reductions in labor inputs, the required tooling and machining centers, and work-in-process inventory.[13]

The use of AM can allow manufacturers to reduce the amount of labor needed in the manufacturing process, as fewer parts/sub-assemblies mean fewer resources required to assemble those components. In some cases, as when using additive manufacturing to produce single-piece systems, labor inputs can be limited simply to the loading and unloading of machines.

AM also allows some manufacturers to alter their production processes by reducing the amount of tooling necessary to manufacture parts. Investment in tooling used in conventional manufacturing techniques such as die casting, injection molding, and forging can make up a significant portion of production costs, and AM can eliminate the need for tooling altogether.[14]

Researchers in Italy, for example, conducted a study in which they examined AM's impact on production factors, including labor and material inputs, on a fluorescent lamp holder traditionally manufactured using injection molding. By redesigning the product to be a single piece and by employing AM to produce the part, the researchers were able to demonstrate reductions in labor inputs—specifically, those related to assembly. Using traditional manufacturing, assembly costs were $.035 per part, equating, at high volumes, to 8.8 percent of the total part costs. AM reduced assembly costs by 66 percent, to $.012 per part.[15]

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Another study by some of the same researchers, this time of model airplane landing gear assemblies, demonstrated AM's ability to reduce not only assembly costs, but tooling costs as well. Traditionally, the manufacturer die cast and then collected the parts for the landing gear assembly; the investment in die cast tooling accounted for 91 to 99 percent of total part cost, depending on production volume. The use of AM eliminated the need to develop and produce tooling—and, after the manufacturer redesigned the assembly as a single-piece system, also eliminated assembly costs. With this dramatic cost reduction, using AM became cost-competitive at low production volumes.[16]

The Italian researchers' examples illustrate the potential benefits of using AM to reduce labor and tooling costs in the supply chain. They also provide guidance on where to seek opportunities for improved supply chain performance: Companies looking to reduce production costs through AM should look for opportunities where multiple individual piece parts are produced using tooling in low volumes and then assembled manually. They may also want to consider AM's additional cost reduction impacts, particularly with regard to reducing the inventory levels needed for work in process, tooling, and finite planning.

Reducing or eliminating assembly inputs carries significant implications, as the types versus amount of labor required to produce a part influences where that part can be produced and still remain economically competitive. With higher-skilled AM labor needed, lower-wage, lower-skill countries could become less attractive locations for production facilities. Thus, manufacturers may begin to consider shifting production back to higher-wage countries for certain types of products.

It is also important to note that the rapid pace of change that currently characterizes AM—including advancements in production speed, the increasing availability of new materials, and, in turn, ever-expanding opportunities—mean that AM's applicability to a given manufacturing area should be regularly considered. Ongoing advancements mean that new opportunities for simplifying production and reducing costs may arise in the future.

Action items:

- Review current product and part designs (and challenge design engineers) to ascertain which components can be consolidated into a single object to get a better sense as to whether AM can help reduce the number of parts needed.

- Ascertain the portion of production costs comprised of tooling, assembly labor, and inventory costs, and compare that to the production costs of a comparable AM approach to determine if AM can produce products of comparable value at a lower overall production cost.

- Estimate the time it would take for a comparable AM approach to "repay" its initial start-up investment and begin to deliver cost savings over a traditional manufacturing approach.

Lowering risk by providing a contingency plan

MANUFACTURERS need not choose between AM and conventional manufacturing techniques—the two can coexist in a production system. In fact, when used in conjunction with traditional manufacturing, 3D printing may improve performance by reducing supply chain risk, providing manufacturers with a contingency means of production if their primary means of production is incapacitated. The use of AM in this way could support uninterrupted deliveries to customers even if the conventional supply chain were disrupted.

AM can also be used in a back-up capacity. Production process disruptions can be unpredictable, requiring contingency processes to be flexible enough to work on short notice and in unanticipated or urgent circumstances. AM production systems are flexible and configurable, able to produce many different parts without incurring additional costs such as tooling development. Additionally, 3D printing is most cost-effective in low production quantities, so it can be used in a short-term application, bridging the gap to a longer-term repair or solution.[17]

The challenge with using AM as a contingency means of production to reduce supply chain risk is that the printed parts must match the functionality of those produced using conventional techniques. Some companies propose to address this concern by over-engineering (for example, employing materials that far exceed the design requirements) the AM-produced part so they are certain it will meet design specifications. The resulting contingency components may be more expensive, but when the cost of production downtime can run into thousands or tens of thousands of dollars per hour, the tradeoff may be worth it.

Opportunities for using 3D printing as a contingency means of production may also be limited to items critical enough to justify the investment in AM systems, or to those that can be low-utilization (by design). However, if systems can be flexible, able to be repurposed for other pursuits such as prototyping and final production, a general AM strategy might reasonably include contingent production capabilities without substantively increasing overall investment in AM technology.

Action items:

- Create a contingency plan for using AM in the event of a supply chain disruption. Develop a plan for using AM as a short-term application to bridge the gap until a longer-term solution is developed.

- Consider running a trial of AM-produced parts in advance to help ensure that their functionality will match those of conventionally produced parts so production and quality will not suffer in an emergency situation. Also evaluate whether other contingency design approaches (for example, overbuilding) can address quality and functionality concerns.

Improving process flexibility, reacting faster to demand

WE define supply chain flexibility as the ability to react to changing requirements. The use of AM can improve supply chain process flexibility in two primary ways:

- AM can reduce the time and resources necessary to design and develop new products. This compression in product development lead time and the corresponding decrease in costs can help companies react more rapidly to changing market preferences.[18]
- AM can reduce the time and resources required to change over production resources from one product type to the next. This capability allows manufacturers to shorten lead times, react more quickly to changes in customer demand, and reduce required levels of finished goods inventory.[19]

When companies have the flexibility to easily switch production designs, they can personalize end products on a mass scale.

A luxury car manufacturer, for example, has used AM to shorten its product design cycle time during its product development process and respond more quickly to market changes. In developing the air manifold for a V8 engine, the company was able to quickly progress through multiple design iterations and produce 17 prototype examples; the lead time to print each prototype was only 1.5 days per manifold. AM also allowed the company to forego the need for prototype tooling. Overall, the company estimates that its product development cycle has shrunk by 50 percent, from twelve months to six.[20]

The aircraft spare parts industry has also studied ways to improve supply chain flexibility by using AM to shorten lead times to customers. Due to the number of parts in a plane—a Boeing airliner can contain up to 4 million parts—and the relative infrequency with which some parts are replaced, the industry experiences great variation in customer demand. While some parts have regular maintenance schedules or replacement requirements, others do not, making it difficult to predict when a customer will need a specific component; by extension, this makes it difficult to accurately predict and manage inventory. Researchers in Finland have listed the theoretical benefits of using AM to quickly produce spare parts, proposing a model of decentralized rapid-manufacturing centers using AM to replace the warehouse space used to store low-inventory, sporadically needed components and associated tooling. The benefits included decreased tooling costs, reduced production lead times for small batches, and reduced inventory costs.[21]

When companies have the flexibility to easily switch production designs, they can personalize end products on a mass scale. In the toy industry, this has given consumers the opportunity to design customized versions of action figures and other figurines online, which can then be rapidly printed to order and shipped. Blizzard Entertainment has used this technique to customize characters from its computer game World of Warcraft based on customer preferences. With the freedom to print outside of traditionally structured factories, companies can create these mass-customized products on-site for streamlined distribution.[22]

Action items:

- Assess the current product design cycle time to determine where AM might help save time.

- Undertake an inventory of sporadically needed parts and components and the costs associated with manufacturing and warehousing them, along with average length of time in the warehouse and the frequency of need for and storage of tooling, to determine the potential efficiencies that might be realized by employing AM for these components.

- Determine the level of need within your target customers for mass customization capabilities to ascertain where AM might be most effective.

Redesigning supply chain networks to decentralized, distributed production networks

AS AM technology improves and becomes more suitable for more types of end-use product production, AM may allow for the redesign of supply chains to better meet customer needs. Indeed, this may represent its most dramatic impact on the supply chain.

"Distributed production on demand"—on-demand production in distributed locations—represents one scenario in which AM can enable a redesign of the supply chain to better meet customers' needs. In this scenario, a decentralized network of 3D printers replaces some or all of the centralized production facilities that use conventional equipment. Fabricating objects at or near the point of use reduces the inventories required to support customer availability expectations, significantly reduces lead time, and reduces dependency on forecast accuracy. These benefits arise because the distributed production on demand supply chain is flexible enough to respond to unpredictable customer demand without incurring additional costs, such as transportation, customs, taxes, and others associated with logistics.[23]

> Mass adoption of this distributed production model could have far-reaching effects on the global economy.

When taken to the extreme in a consumer goods setting, the use of AM-supported distributed production networks might eliminate the need for seller-controlled means of production. Theoretically, consumers could purchase access to designs and produce goods at home or at other production-capable locations. Mass adoption of this distributed production model could have far-reaching effects on the global economy—specifically, on global trade imbalances, as AM technology could enable countries that have traditionally imported most goods to reduce their reliance on foreign production.[24] By purchasing the right to manufacture a product at home rather than purchasing the product through traditional retail channels, some estimate that consumers might save 80 to 90 percent of the purchase cost.[25]

Leaders in the logistics industry have taken notice of AM's potential to disrupt traditional supply chains through the use of distributed production on demand. UPS has experimented with on-demand AM services in UPS stores, piloting a program in six markets in September 2014 and, in the months since, expanding AM services to nearly 100 locations throughout the United States.[26]

NASA and the US Navy are also currently experimenting with using AM to improve supply chain performance. NASA is testing

AM for in-space manufacturing on the International Space Station, enabling on-site production of hardware upgrades and tools rather than requiring a space launch to deliver them. The Navy is investigating the use of AM to produce spare parts while at sea.[27]

Just as AM enables distributed production networks, it also enables manufacturers to enter new markets at a lower relative cost. With AM capabilities, manufacturers can rely less on economies of scale to enable local production. Rather, production can take place on a smaller scale with lower ramp-up costs.

Action items:

- Review the need, if any, within your organization for enabling a distributed production model. Understand what resources and capabilities would need to be put in place to make this model function effectively, what the investment costs might be, and whether (and when) those costs would be offset in an AM-enabled model. Consider how this model may allow your organization to scale.

- Assess the functionality and quality of products manufactured in a distributed production model to ensure that the products are comparable to those manufactured and shipped via a more conventional model.

- Consider where it may be feasible to expand to new markets through the use of AM capabilities.

Conclusion

AM technology represents a potentially valuable area for investigation and investment as companies consider ways to improve supply chain performance. Indeed, Deloitte's research has found that higher-performing supply chain leaders are already using AM in this way.[28] AM's total impact on supply chain performance remains to be seen. Some companies and industries will realize benefits within the boundaries of the existing supply chain structures, while others will use the technology to rethink and revamp much about the way they go to market.

Before AM can reach its full potential for expanding supply chain possibilities, developers will need to overcome a number of challenges, including creating more AM-specific materials aimed at fulfilling user requirements. Training cannot be neglected, either; companies need engineers familiar with—and able to operate—AM software and printers, and capable of envisioning how the technology can produce products that meet consumer expectations. Finally, companies using AM to support a distributed manufacturing strategy will need to take steps to secure their designs and data to guard against unauthorized duplication or tampering.

Adopting AM to improve supply chain performance is a multi-step process. Companies considering adopting the technology first need to consider their objective: Do they want to simply improve supply chain performance while operating within the same design? Or do they wish to fundamentally change the way they produce and deliver their products? In the course of answering these questions, it will be important to consider these key calls to action:

Leverage AM to improve supply chain performance within the same design rubric. Companies wishing to improve their existing supply chain performance by making incremental changes should consider looking for opportunities to reduce material inputs to the production process. Eliminating material waste—especially if the material cost makes up a major portion of the overall product cost—is a tangible benefit that supports the business case for incorporating AM technology. Once engineers have identified these savings, managers should look for further opportunities to reduce assembly steps, thereby simplifying the production process. Eliminating assembly steps and their associated costs is incremental to the material cost savings, but is often harder to justify on its own.

Examine how AM capabilities can enable and support fundamental changes to production and delivery. Companies wishing to fundamentally change the way their products are manufactured and delivered should begin the process differently. Rather than surveying their own products and identifying which production processes would benefit most from introducing AM technology—as those looking to incrementally improve the production process should do—they should look closely at their customers' resupply and delivery needs to determine which of those needs would benefit most from a radically different supply chain. While managers looking to incrementally improve supply chain performance may view AM as a way to reduce costs, those looking to fundamentally rethink their supply chains must consider what additional value AM technology can provide to customers and how to collaborate with design/engineering.

Regardless of where they begin, companies would be well advised to consider how the continuing evolution of AM capabilities stands to alter supply chains for themselves and those they compete against in serving their customers.

Endnotes

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