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Additive Manufacturing's Disruptive Impact on the Supply Chain

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"It is my hope that when people look back on the Fourth Industrial Revolution 50 years from now, they are going to be talking less about the Internet of Things (IoT) and more about how we removed 30%-50% of material that we had in automobiles and how everything has become more efficient."

– Ric Fulop, CEO and Co-founder, Desktop Metal

Manufacturing products have evolved over centuries with continuous technological advancements. Manual tools have given way to highly technical machines, which has decreased the time it takes to machine a part and reduced the physical demands on the operator. However, the basic manufacturing premise has remained relatively constant: Raw material is shaped, formed, cut, etc. to produce a final product. These traditional manufacturing methods can be termed subtractive manufacturing, as material is removed to create the final product.

Additive manufacturing provides the potential to disrupt traditional manufacturing methods.

Additive manufacturing provides the potential to disrupt traditional manufacturing methods. Additive manufacturing, also known as 3D printing, instead of removing material adds material, layer by layer, in the shape and structure intended until the final product is completed. The advantage of this method includes less material waste, ability to design complex shapes, design freedom and rapid prototyping. However, while additive manufacturing has been around since the 1980s, it has not replaced traditional manufacturing, and it may yet be several years before it has a significant impact on most manufacturers (Attaran, 2017).

This is not to say that additive manufacturing is a fad, as the trend for 3D printing utilization continues to grow and this trend is not changing anytime soon. In 2011, the global revenue for additive manufactured goods was $623.6 million USD and this is projected to increase to $50 billion USD by 2030 (Tofail et al, 2018).

In addition to technological improvements and additional applications required for the realization of a disruptive shift felt by additive manufacturing, integration of additive manufacturing in the supply chain must be realized (Chan et al, 2018). A typical supply chain begins with raw material that gets shipped to two or three tiers of suppliers before ending up at the Original Equipment Manufacturer (OEM) factory to assemble the final product. This network uses traditional manufacturing techniques that require the raw material to be machined into components, sub assembled and then assembled with other parts. In the case of a molded part, the mold is machined from raw material, then material is injected into the mold, sub assembled and then goes to final assembly. This chain of events is not compatible with additive manufacturing, as the process for working with raw material varies tremendously. Disruption of the supply chain process would be required in order to realize the advantages of additive manufacturing.

People

Now (1-2 years)

Traditional manufacturing has evolved over time, due to technological advancements, and design for manufacturing has evolved along with it. This has had the benefit of over a century of application and refinement. Additive manufacturing, being a relatively new technology has not had the same amount of trial and error, and applications. In addition, the process for additive manufacturing is significantly different from traditional manufacturing. The restrictions applied to the design criteria for traditional manufacturing are removed in additive manufacturing, as the layer-by-layer building of the part increases the design freedom (Mellor et al, 2014). As such, new design principles need to be developed for additive manufacturing, and currently, there is a lack of standardization, which has hindered quality control of additive manufacturing (Pereira et al, 2019). In addition, as many customers are demanding replacement parts through this new process, additional testing is required to validate that the additive process achieves the same level of quality and performance as the traditionally produced part.

Without standardization, personnel responsible for implementing additive manufacturing rely on design for traditional manufacturing principles as a basis. They would then need to implement a trial and error technique before coming up with the appropriate design or process. This has contributed to the slow adoption of additive manufacturing in some industries or the lack of integration of additive manufacturing into traditional manufacturing processes. An additional challenges include:

1. High equipment cost
2. Limited raw material viability
3. Technical complexity (coding)
4. Low speeds

All of these factors are improving rapidly, which will increase adoption.

Near (2-5 years)

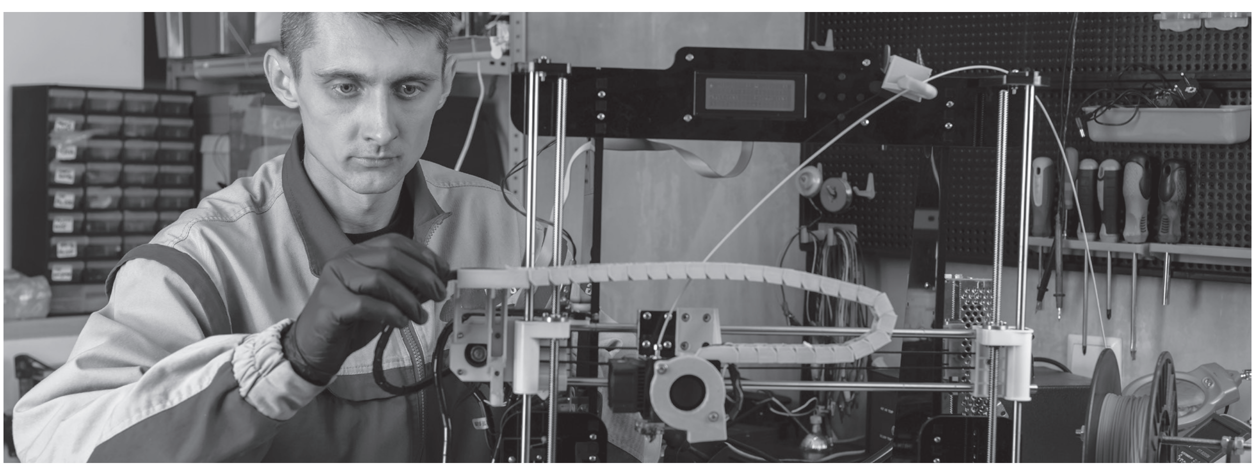
The health care industry has been one of the early successful adopters of additive manufacturing, and this industry will most likely continue expanding their adoption of the technology (Silva and Rezende, 2013). The consumer, in this case, the patient, benefits most from additive manufacturing due to the customizability of products. In particular, the hearing aid, dental implants, bone and joint implants (spine, shoulder, hip) are using additive manufacturing.

The adoption of additive manufacturing in post-secondary institutions will provide the talent to administer the technology in industry. Various institutions house additive machines, allowing researchers to experiment with and learn the technologies. Short courses are beginning to be delivered, with the anticipation that additive manufacturing principles will be embedded into curriculum. The arrival of additive manufacturing talent in the workforce will accelerate the adoption of the technology in industry.

Far (+ 5 years)

Increased adoption and integration of additive manufacturing into the supply chain will have an impact on the structure of the supply chain and the relationships between suppliers (Mellor, 2014). The location of suppliers may become more distributed to be closer to the demand. Additive manufacturing requires raw material and CAD data as the inputs, thereby potentially decreasing the number of steps in the supply chain process (Mellor, 2014). The structure of the factory may also change from a large assembly plant concept to small factories (Silva and Rezende, 2013). In some industries, products will be designed and produced at one facility and sent directly to customers, without retailers (Silva and Rezende, 2013).

Since additive manufacturing differs significantly from traditional manufacturing, new design guidelines will need to be developed and implemented, which will require a different skillset for designers. Ultimately, this will create new and different types of jobs, resulting in changes in work practices and structure (Mellor et al, 2014). By that point, the demand for talent from post-secondary institutions will force the curriculum changes to include additive manufacturing principles.



Process

Now (1-2 years)

Additive Manufacturing is changing this dynamic by allowing tools to be made faster and cheaper through 3D printing. Part of the design and development of a product involves making a prototype to allow for physical inspection of the fit, form and function of the part. This is a critical step in the process, in order to determine the proof of concept before entering the production phase. Once in production, it is very costly to make a change to the part design, and the prototype provides the closest understanding of the design effectiveness. Prototyped parts are generally made with limited durability and functionality, only to prove out the concept, and is thus less expensive to produce than a single production part. However, traditional manufacturing prototypes can be relatively expensive, as a mold or cast needs to be made for a single or small batch of parts. If a change needs to be made, a new or redesigned mold would need to be developed.

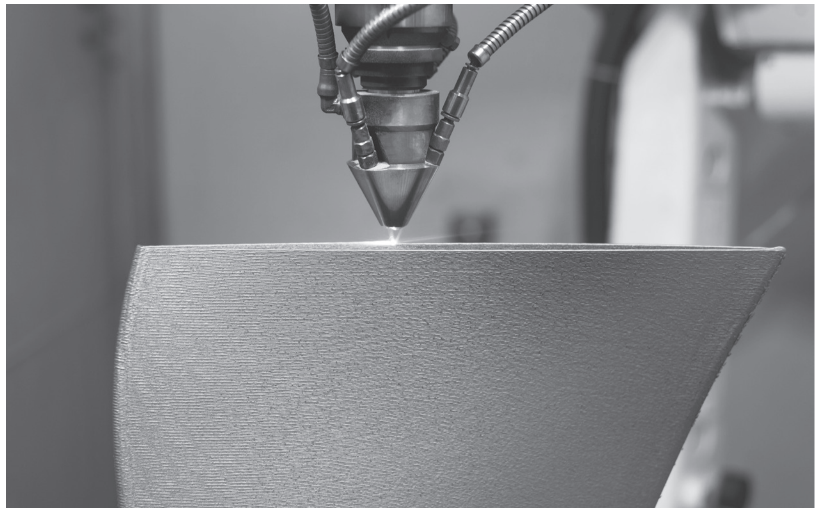
The introduction of additive manufacturing was first applied to making prototypes (Attaran, 2017). 3D printing an object does not involve tooling, allowing the supplier to reduce design time, as it is not necessary to create a mold for prototype parts (Chan et al, 2018). Rather, the part can be designed in CAD and sent directly to a 3D printer, which is then printed in a relatively short period of time, depending on the size of the part. Modifications that need to be made, based on the evaluation of the prototype, can be performed quickly and then printed again. The total time and ultimately cost of prototyping with 3D printers is significantly less than traditional prototyping, which decreases the amount of time a product can get to market (Attaran, 2017).

While prototyping is still the primary application, production parts are being made utilizing this technology, albeit in small batch production. The additive manufacturing process removes constraints on the part design, as it does not need to fit a tool that requires machining. This results in the ability to create complex parts, as the part is built layer by layer, rather than utilizing machines to remove material, which is challenging in deep locations of the part. Also, similar to prototyping, a change to the production part can be easily performed, with a change in the design and then sent to the 3D printer, allowing for mass customization of parts. This has been capitalized on by the aerospace industry, due to the complex parts with small series customization, and the health care industry due to the need for customized solutions to address specific patients (Silva and Rezende, 2013). In addition, the advancement in raw materials available for use increases the number of finished products that can be produced using additive manufacturing.

However, in situations where there is a large volume production (mass manufacturing), with low complexity, and high precision, traditional manufacturing currently is the production method of choice (Pereira et al, 2019). Current 3D machines provide challenges with respect to part consistency, surface finish and tolerances, compared to traditional manufacturing (Pereira et al, 2019). As the volume of production increases, traditional manufacturing becomes a more cost-effective option. This has resulted in little effect on the supply chain, as large manufacturers still rely on traditional manufacturing.

Near (2-5 years)

While the advantages of prototyping with additive manufacturing will continue to be exploited, mass customization will begin to affect the supply chain. Additive manufacturing will allow for easier product differentiation (Chan et al, 2018). Industries in which consumers value personalized products will take advantage of additive manufacturing, as it is more cost effective to print parts with customized variations than it is to use traditional manufacturing processes. This will allow for a small quantity production of a part and then efficiently change the design to produce a subsequent small quantity production. This will have the effect of changing the traditional supply chain model (Chan et al, 2018).



The spare parts supply chain is one industry that has the potential for disruption due to the additive manufacturing advantages of small quantity production. Traditional manufacturing processes result in larger inventories in order to provide replacement parts in a timely manner. Since the primary benefit of traditional manufacturing is mass production, it is not cost effective to produce a batch of one, resulting in over-production in order to store additional parts. In addition, suppliers would be required to house tooling of parts that are no longer in production, in order to provide the ability to produce out of stock parts. Additive manufacturing would reduce inventory requirements and decrease lead times, resulting in simpler supply chains (Khajavi et al, 2014).

Far (+ 5 years)

Reducing cost throughout the supply chain is one of the goals of OEMs, in order to remain competitive. Barz et al (2016) developed a model to study the effects of additive manufacturing on the supply chain using predictable factors such as functional integration of parts and resource efficiency. They found that because additive manufacturing can produce complex products in less steps, in some cases one step, not only would costs within a company decrease, but it would decrease the need for steps in the supply chain, as OEMs could print various parts (Barz et al, 2016). Transport costs are another factor in the supply chain. Since additive manufacturing reduces the amount of material required for production, the quantity of goods to be transported will change, resulting in relocation of production sites closer to customers (Barz et al, 2016). In other words, smaller production facilities can be located near the demand, instead of shipping from centralized locations. Upstream, additive manufacturing will affect the raw materials amount and delivery, as well as the number of component manufacturers. Downstream, warehousing and the retailer network will be reduced due to production on demand (Silva and Rezende, 2013).

An example of such an additive manufacturing situation would require the raw material to be shipped to the additive supplier, which would create a finished part that could then be shipped to the OEM for final assembly (Chan et al, 2018). This eliminates at least one supplier in the network compared to traditional manufacturing. This shorter supply chain is due to the additive manufacturing ability to produce a part that requires no assembly, which in traditional manufacturing may require components from multiple suppliers for assembly (Chan et al, 2018). In the mold supply chain example, a mold is not required, eliminating that step altogether. However, this ideal state has not yet been realized.

Technology Evolution

Now (1-2 years)

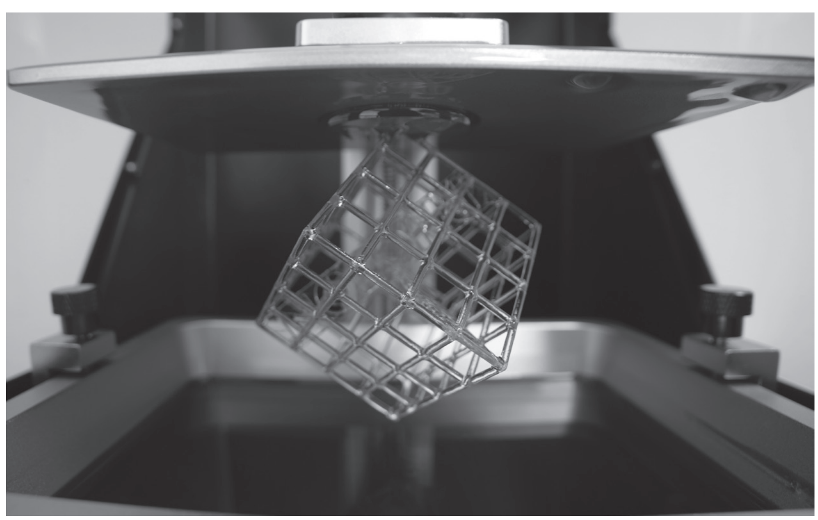
Currently, there are a variety of additive manufacturing technologies using a variety of materials to build parts. These technologies and materials have enabled industries to create prototype parts and, in some cases, production parts. The method of additive manufacturing, which continuously deposits material layer-by-layer, provides the opportunity to make complex parts, compared to traditional manufacturing. However, one drawback of 3D printing methods is the production time for large lots (Silva and Rezende, 2013). This results in the usage of additive manufacturing for small batch production, as the cost of traditional manufacturing for small lot sizes is greater due to the tooling requirements.

In the case of the aerospace industry, additive manufacturing has been successful due to the requirements of complex parts in small production runs. A glimpse of the future state of additive manufacturing has been provided with an aerospace example. The aircraft-component maker Moog Inc. combined blockchain and 3D printing, by ordering a part from New Zealand to be printed in Los Angeles, while the airline was traversing that distance, with the part to be installed upon arrival (Shah, 2019). This demonstrates the impact additive manufacturing can have on the supply chain, in combination with other technologies, such as blockchain.

The technological effect on the supply chain has not yet provided a significant impact. In order for additive manufacturing technology to have an impact, it must become faster, autonomous and more reliable (Attaran, 2017). The speed of production has limited the technology to be used in small batch production, since it is more cost effective with smaller production runs compared to traditional manufacturing. Although 3D printers run on their own, there is a significant interaction to monitor the parts for quality and maintenance. Compared to traditional manufacturing, additive manufacturing has quality challenges as the 3D printing process can result in differences between parts for the same design (Pereira et al, 2019).

Near (2-5 years)

Although additive manufacturing has been around for decades, and there have been successful applications of the technology, in general, it hasn't been integrated into supply chains. As the technology continues to improve, materials advance and equipment costs decrease, utilization of additive manufacturing will continue to increase, with the addition of new adopters, and current users expanding their product applications. Additive manufacturing machine makers are changing their designs to significantly improve part production speeds. In addition, the cost of the investment and the cost of production will decrease,

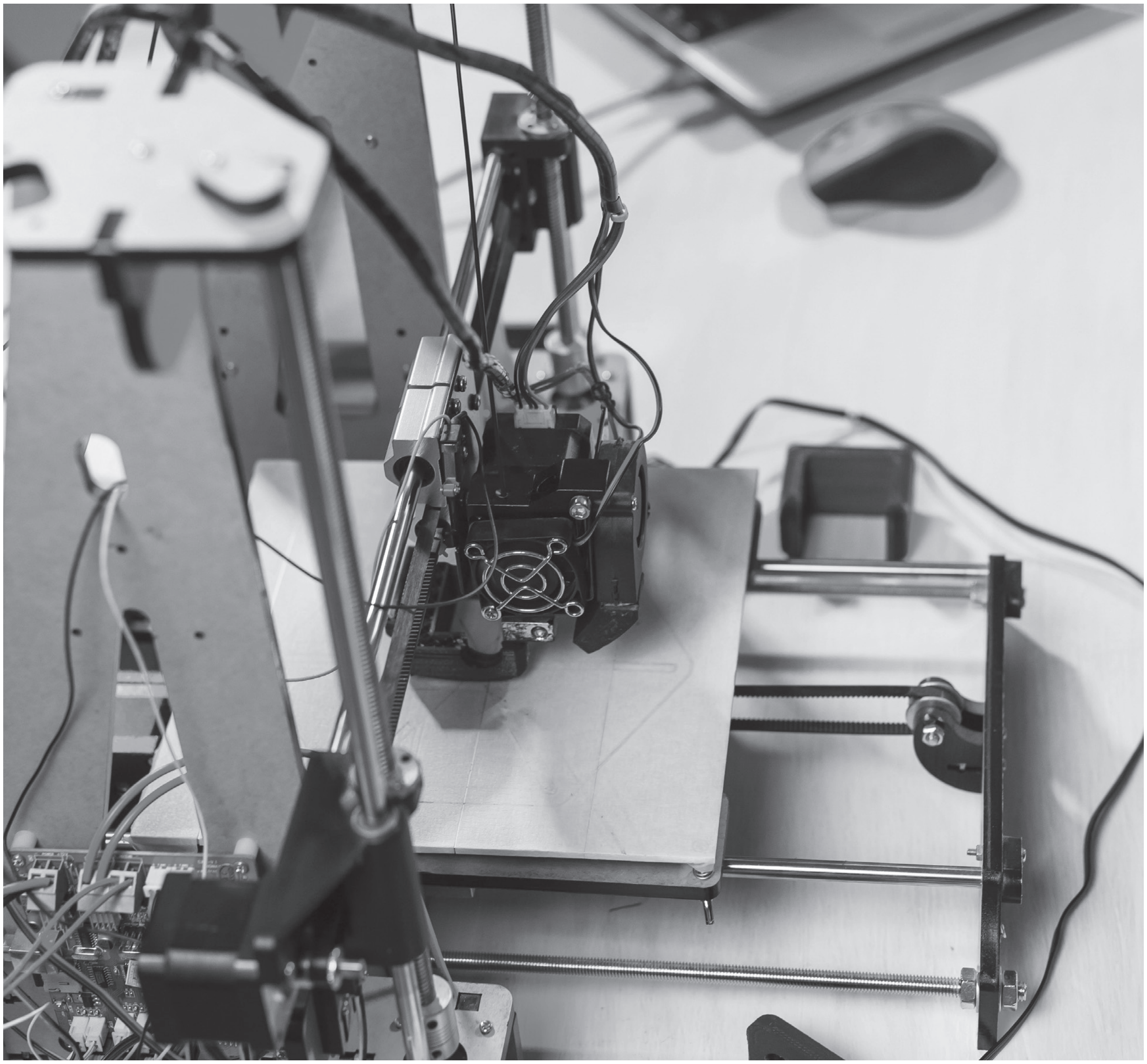


while the technology will improve to deliver higher quality and an increased variety of parts. While it may be premature to state that additive manufacturing will replace traditional manufacturing, it will most likely have a significant impact on the supply chain.
With advances in materials and technology, additive manufacturing machines will be able to increase the amount of production parts to supplement certain parts and/ or industries with this technology. However, at this stage, additive manufacturing is not intended to replace traditional manufacturing, rather, it would be integrated into the production processes (Silva & Rezende, 2013).

Far (+ 5 years)

In industries that allow for and require mass customization, as material development improves, there will be a greater utilization of additive manufacturing. This will have an effect on the supply chain, as the products can be made locally, which will result in decreased transportation costs, as well as stocking (Silva & Rezende, 2013). This has been modeled by Khajavi et al (2014) as they studied the impact on the spare parts supply chain. With the current technology, centralized locations are more cost effective. However, with the improvement in machine automation, decreases in machine cost, and shorter production times, it was found that a distributed model with production sites located near the customers would be more cost effective (Khajavi et al, 2014). This will result in the development of new logistics models. Traditional assembly lines will not be required in these scenarios, and parts will be produced in batches in small factories. Also, these products can be shipped directly to the customer, with the potential of eliminating the need for retailers (Silva & Rezende, 2013).

While there is debate about whether or not additive manufacturing will replace traditional manufacturing, it does seem that additive manufacturing will disrupt the manufacturing industry, particularly with respect to the supply chain. Industries that produce parts in small batch sizes, have complex designs and require customization that will benefit most from additive manufacturing. Other industries will integrate additive manufacturing into their traditional manufacturing processes. In both scenarios, the supply chain will be altered, as additive manufacturing requires less steps in the supply chain, and a distributed supply chain model has been shown to be more cost effective when implementing additive manufacturing. This will occur with further technological developments and cost reductions in additive machines. It will also result in a shift in the types of skill sets required to administer additive manufacturing technologies and supply chain management.



Action Items

- Continue developing additive manufacturing technologies that provide higher automation, lower acquisition price and shorter production time.
- Develop design for additive manufacturing guidelines and standards to improve quality, testing and consistency of parts.
- Develop educational programs specific to additive manufacturing to increase the talent to administer additive manufacturing technologies.
- Investigate opportunities to integrate additive manufacturing into traditional manufacturing.
- Evaluate current supply chain models and identify opportunities to adopt alternative models, based on the impact of additive manufacturing.

About Automation Alley

Automation Alley is the World Economic Forum's Advanced Manufacturing Hub (AMHUB) for North America and a nonprofit Industry 4.0 knowledge center with a global outlook and a regional focus. We facilitate public-private partnerships by connecting industry, education and government to fuel Michigan's economy and accelerate innovation. Our programs give businesses a competitive advantage by helping them along every step of their digital transformation journey. We obsess over disruptive technologies like AI, the Internet of Things and automation, and work hard to make these complex concepts easier for companies to understand and implement.

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