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3D Printing in Supply Chain

Matthew N. O. Sadiku[1], Paul A. Adekunte[2], Janet O. Sadiku[3]

[1]Roy G. Perry College of Engineering, Prairie View A&M University, Prairie View, TX, USA
[2]International Institute of Professional Security, Lagos, Nigeria
[3]Juliana King University, Houston, TX, USA

ABSTRACT

3D printing is a process which uses a three-dimensional digital model to create a physical object by adding many thin layers of material in succession in order to produce finished goods. The term "additive manufacturing" is used to explain this principle. With 3D printing technology, a design file can transform directly to a product, skipping many traditional manufacturing steps. Various types of technologies are applied to create complex designs and customizable products on an individual basis with less effort than traditional manufacturing processes. The objective of this paper is to explore the impact of 3D printing technology on supply chain.

KEYWORDS: *3D printing (3DP), additive manufacturing, AM, supply chain, supply chain management, SCM, 3D printing in supply chain*

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INTRODUCTION

Although three-dimensional (3D) printing, also known as additive manufacturing, has been a staple in hobbyists' lives for years, its popularity in industrial applications is now rapidly rising. It refers to the production process in which a 3D object is fabricated from a digital model file with physical materials typically being added together or etched layer by layer. 3D printing is used in many industries, including aerospace, automotive, consumer goods, healthcare, and dentistry. 3D printing's primary role in supply chains revolves around manufacturing. Many manufacturers use it for small-batch or custom orders because of its fast turnaround time. The adoption of 3D printing is not only transforming supply chains but also delivering significant benefits to customers by enhancing efficiency, reducing costs and enabling flexible production across various industries.

While traditional printers apply ink to paper to reproduce text and images, 3D printers employ materials to produce a three-dimensional object. The greatest potential of 3D printers lies in their capacity to streamline production processes. 3D printing is one of the technologies with the most potential to transform logistics and supply chain. The technology is also helping to create more sustainable supply chains. It reduces waste to a minimum because material is added (hence the term "additive") in the precise quantities needed to make an object. AM technology leads to the disruptive innovations that creates a global impact on the logistics of industries and the supply chain. The main competence of this technology is to fabricate the products closer to the expectations of customers around the world and to customize those products in real time [1].

WHAT IS 3D PRINTING?

3D printing (also known as additive manufacturing (AM) or rapid prototyping (RP)) was invented in the early 1980s by Charles Hull, who is regarded as the father of 3D printing. Since then it has been used in manufacturing, automotive, electronics, aviation, aerospace, aeronautics, engineering, architecture, pharmaceutics, consumer products, education, entertainment, medicine, space missions, the military, chemical industry, maritime industry, printing industry, and jewelry industry [2].

A 3D printer works by "printing" objects. Instead of using ink, it uses more substantive materials–plastics, metal, rubber, and the like. It scans an object–or takes an existing scan of an object–and slices it into layers, which can then convert into a physical object. Layer by layer, the 3D printer can replicate images created in CAD programs. In other words, 3D printing instructs a computer to apply layer upon layer of a specific material (such as plastic or metal) until the final product is built. This is distinct from conventional manufacturing methods, which often rely on removal (by cutting, drilling, chopping, grinding, forging, etc.) instead of addition. Models can be multi-colored to highlight important features, such as tumors, cavities, and vascular tracks. 3DP technology can build a 3D object in almost any shape imaginable as defined in a computer-aided design (CAD) file. It is additive technology as distinct from traditional manufacturing techniques, which are subtractive processes in which material is removed by cutting or drilling [3]. A digital design, material, and a 3D printer are all you need to print a 3D product. Figure 1 shows how 3D printer works [4].

3D printing has started breaking through into the mainstream in recent years, with some models becoming affordable enough for home use. Many industries and professions around the world now use 3D printing. It plays a key role in making companies more competitive. The gap between industry and graduating students can be bridged by including the same cutting-edge tools, such as 3D printing, professionals use every day into the curriculum. There are 3D printed homes, prosthetics, surgical devices, drones, hearing aids, and electric engine components. As shown in Figure 2, 3D printing involves three steps [5]. A typical 3D printer is shown in Figure 3 [6].

3D PRINTING IN SUPPLY CHAIN

While many people associate 3D printing products and services with do-it-yourself projects and fun, its penetration rate in the supply chain industry is high. Since this technology can accelerate typical production and backend processes, it has become a large part of logistics and supply chain. Additive manufacturing represents a major opportunity for companies to re-engineer their buy-make-move-fulfill supply chain for competitive advantage.

Supply chain is one of the most stable and traditional industries. Figure 4 shows a symbol of supply chain [7]. 3D printing in supply chain markets is set to have a major impact. Today, the technology has the potential to become the basis for new solutions in supply chain management. The 3D supply chains are accepted as less complex and speedy by heart when compared to traditional supply chains. Traditionally, raw materials or components are supplied from suppliers, assembled in manufacturers and shipped to customers through retailers or distribution centers. 3D printing technology can decrease the number of stages in the traditional supply chain because of needing fewer components and it is able to manufacture products near the customers. It enables organizations to bypass the traditional supply chain and manufacture a product themselves with a digital design. On a strict unit cost comparison, 3D printing cannot compete with traditional manufacturing at scale. Figure 5 compares traditional supply chain with 3D printing supply chain [8], while Figure 6 shows supply chain 3D printing [9].

EXAMPLES OF 3D PRINTING SUPPLY CHAIN

Leading automotive manufacturers were the early adopters of additive manufacturing.

Automakers including General Motors, BMW, Ford, Daimler, Mercedes Benz, and Volkswagen have utilized AM for the production of specialized vehicle components or parts for numerous years. They are all improving their service using the technology. Logistics companies such as DHL and UPS are already benefitting from on-demand printing by providing extended distribution facilities and partnering with 3D printing companies. Here are a few organizations using additive manufacturing in their supply chain [10]:

- *Vestas:* Vestas, based in Denmark, is a global wind energy leader that designs, manufactures, installs, and services wind turbines across the globe. For Vestas, many critical tools and parts are needed at each manufacturing facility and installation site. Tools like inspection gauges are needed to ensure precision and accuracy in the manufacturing and installation processes. Vestas historically has outsourced the manufacturing of many parts to multiple third party vendors around the world. Detailed manufacturing instructions would be provided for each part. The finished parts would then be sent to Vestas's manufacturing facilities and installation sites. Vestas employees can print up-to-spec parts on a moment's notice, anywhere in the world, without the need for specialists.
- *US Army*: The US Army's Fort Irwin National Training Center (NTC) is a major training base. Located in San Bernardino, CA, the NTC provides realistic joint and combined arms training to develop the US Army's soldiers and leaders for the battlefield. The Center requires many specialized resources, such as military-grade vehicles and equipment, to provide realistic

battlefield training. With metal 3D printing and a desktop 3D printer, bringing additive manufacturing on-site to Fort Irwin through the Digital Forge has helped the Army NTC create readiness factors and maintain availability of equipment and vehicles to be used in training. Figure 7 shows a soldier using 3D printer [10].

- *Nieka Systems:* This is a Canadian manufacturer of borate fusion sample prep equipment for customers in the mining and cement production industries. Using Nieka's machines, ore and cement samples can be fused into glass discs in preparation for precise compositional analysis, and to assist with quality control. Nieka's machines work by mixing and dissolving material samples in molten borate flux in a platinum crucible at temperatures exceeding 1000 degrees Celsius. Nieka was a growing business: its products were available to customers in over 20 countries around the world. But due to the slow lead times and uncertainties associated with using the service bureaus, Nieka faced growing uncertainties about their ability to keep up with global demand for their products. Bringing additive manufacturing in-house with the Metal X system, Nieka has been able to manufacture its Inconel crucible clips in drastically reduced lead times that are consistent and predictable. Figure 8 shows Nieka's molding facility [10].
- *GE:* GE has built a prototype 3D printed aircraft engine, the GE9X[2] that is lighter, faster, and more fuel-efficient than any of its predecessors. The company claims 3D printing enabled it to reduce 855 separate parts to just twelve. GE already have more than 300 3D printers and GE Aviation wants to produce 100,000 additive parts by 2020. Both GE and Airbus have found that the technology allows them to redesign aircraft parts to reduce their weight, saving costly fuel. In the aerospace industry, the Boeing 737s and nearly half of the Airbus A320s will be equipped with the new Leap engines. Developed by General Electric and Safran, they feature a 3D printed carburettor. Figure 9 shows GE's 3D-printed airplane engine [8].

APPLICATIONS OF 3D PRINTING IN SUPPLY CHAIN

Manufacturers, warehouses, and distributors can use this technology to streamline production and reduce downtime, enabling them to bring products to market sooner and make deliveries faster. 3D printing technology creates a close relationship between design, manufacturing, distribution, and marketing. Common areas of applications include the following.

- *Manufacturing:* For manufacturers all over the world, supply chain issues present a major threat to productivity and their ability to meet critical business deadlines. The traditional manufacturing space is a sector that could greatly benefit from 3D printing technology. Manufacturers should look at 3D printing as an investment, because additive manufacturing can help companies save money on parts. Parts can make up anywhere from 20-30% of a company's total inventory expenses, but this would be drastically reduced if organizations were more open to using 3D printing in their manufacturing processes. As the technology has advanced and become more available to manufacturers, 3D printing is expected to become an integral part of many industries' operations and could ultimately help companies achieve their sustainability goals. AM can be a positive influence on manufacturing supply chains if implemented strategically. For example, NASA has been testing AM in zero gravity in hopes of establishing on-demand manufacturing for astronauts. This would allow component parts for maintenance and repair of the international space station to be manufactured in space.
- *Warehousing:* In warehousing, workers can use 3D printers to make safety equipment like hard hats, disposable gloves, or ergonomic inserts to make material handling less risky. They have been introduced into most personal protective equipment domains because they are fast, accurate, and require no human contact. Warehouses save on inventory space and carrying costs since their "parts" are CAD files stored in the cloud and printed immediately on-site. 3D printing enables on-demand, customizable production, reducing lead times, inventory costs, and warehousing needs across industries. Figure 10 shows a DHL warehouse [11].
- *Distribution:* Distributors are using 3D printing technology to improve communication and shorten shipping times. For example, they can use it for packaging and inserts to reduce the likelihood of product damage during distribution. Distributors spend less on transportation because decentralized facilities require shorter trips. If they use 3D-printed packaging and inserts custom-fit to specific products, they may receive fewer damage-related returns.
- *Medical Supply Chain:* The use of 3D printing alters the method in which medicine is practiced, resulting in major changes to manufacturing and distribution systems. For example, medical

equipment manufacturers use it to craft tailor-made prosthetics. Custom-made prostheses can now be produced with less weight improving wearability. The technology is already being applied to manufacture stock items, such as hip and knee implants, and bespoke patient-specific products, such as hearing aids, orthotic insoles for shoes, personalized prosthetics. It seems evident that the use of 3D printers in the medical field can change both the way things are made and how they are distributed.

- *Automotive*: Many automotive companies are already making use of 3D printing to help with prototyping. Ford has been using 3D printing technology since the 1980s. The technology has played a major role in the automotive and aerospace industries to make the lightest practical car or aircraft while securing safety. Not only has the technology simplified the manufacturing of complex materials, but it also cuts out one to two-thirds of the weight, while maintaining the same structural performance as the original parts Spare parts can be produced on demand nearer to the market they serve from designs that are sent electronically across the world. The opportunity now exists to simplify your supply chain by creating in-house 3D printed end-use and spare parts. Figure 11 shows some automotive parts [12].

BENEFITS

3D printing is transforming supply chains by reducing lead times, lowering costs, and enabling more customization. It can help to reduce supply complexities, increase the speed to market of product, reduce global impact, and allow remote locations to print replacement parts. 3D printing is fast, precise, and cost-effective — the three qualities every logistics company strives for. For companies looking to reduce their reliance on a shaky supply chain, 3D printing offers exceptional benefits, savings, and advantages. Other benefits include the following [13]:

- *Speed to Market:* 3D printing allows for on-demand production, which can reduce lead times and speed up time to market. Logistics companies using additive manufacturing benefit from reduced lead times, meaning that they shorten the time between the beginning and end of a process.
- *Decentralization:* 3D printing is a portable technology that can be moved anywhere quickly. Additive manufacturing technologies enable decentralized production. It is anticipated that decentralized AM will be less costly in the future owing to improved automation, decreased prices, and smaller machines. You can have a number of industrial 3D printing systems spread out across a larger number of smaller facilities. This ensures that production will not be majorly delayed by downtime at one or even two locations.
- *Cost Savings:* 3D printing can reduce inventory costs and warehousing costs. 3D printing is an affordable alternative to many standard logistics tools. 3D printing supports profitability of the supplier and potential cost savings to the consumer in many ways.
- *Customization:* 3D printing allows for products to be tailored to customer needs. 3D printing technology provides producers with unrivaled flexibility to personalize solutions to the individual needs of customers and improve the customer experience. 3D printing technology gives manufacturers unprecedented freedom to tailor offers to clients' specific requirements and enhance the customer experience. 3D printing finds its value in the printing of low volume, customer specific items, items that are capable of much greater complexity than is possible through traditional means.
- *Sustainability:* A lot of people are becoming more and more aware of the importance of sustainability, and so it becomes a bigger part of our daily lives. Sustainability is another benefit of 3D printing technology, which minimizes the environmental footprint of products by reducing material usage, energy consumption and waste. 3D printing is a sustainable manufacturing method, which can contribute to your organizations sustainability goals and reduce the impact on the environment. 3D printing can reduce waste, emissions, and raw material use. Environmental impact can be radically reduced as we remove by products from the manufacturing process and cease to ship goods around the globe. 3D printed products need less long-haul transportation resulting in the decline of C02 emissions.
- *Design Freedom:* As 3D printing builds items layer by layer, it enables design freedom. The design freedom of 3D printing allows for products that are customizable or optimized for each customer at greatly reduced costs over approaches using traditional methods.
- *Raw Materials:* Worried about the aluminum shortage jacking up the prices? Today's professional 3D printers can make composites stronger than aluminum, in anywhere from just hours to days. A major new sector of the logistics industry would emerge dealing with the storage

and movement of the raw materials which 'feed' the 3D Printers. As 3D printers become more affordable to the general public, the home delivery market of these materials would increase.

- *Less Waste:* 3D printing produces parts layer by layer. As opposed to subtractive manufacturing methods, additive manufacturing places filament only where it is needed. Less wasted material means fewer transportation and waste disposal costs, while also being more environmentally friendly.

CHALLENGES

In spite of the many advantages of 3D printing for various industries, the technology also comes with some challenges. There are some significant challenges organizations face when integrating 3D printing technology into their manufacturing methods. Not all products can be 3D printed. Companies must address IP, liability and security risks, especially in regulated sectors, to maximize 3D printing's benefits. Other challenges include the following [13]:

- *Lack of Standards:* 3D printing is not standardized. This means product quality can vary from printer to printer, which brings a great deal of risk. Many countries do not recognize 3D printed products as an acceptable manufacturing process, so highly regulated industries might need to wait longer before adopting additive manufacturing.
- *High Costs:* A 3D printer is not cheap; particularly if you are looking to manufacture large volumes of goods that have many layers. Another one of 3D printing's biggest cons is the upfront investment cost. While the average hobbyist can get a printer for a few hundred dollars, industrial-grade versions are more expensive. There is often no justification to support an engineer only focused on 3D printing.
- *Knowledge:* 3D printers are complex machines and employees may find them difficult to operate. This brings some additional costs such as investing time and money in training the right people to use the machines. 3D printers are smaller and more compact than traditional manufacturing installations, and require fewer and less-skilled operators.
- *Intellectual Property Rights*: Issues such as durability, speed, and protection of intellectual property rights have prevented 3D printing from entering mainstream manufacturing. There remain concerns over the freedom to generate items on a 3D printer that may breech intellectual property rights.
- *Cybersecurity:* Data breaches are another concern. Bad actors could reverse engineer designs or hack cloud platforms to steal intellectual property, making CAD files free for public use. The downside of adopting user-friendly technology is that it may be too accessible to consumers.

CONCLUSION

3D printing is a disruptive innovation which will have a far- reaching impact on global supply chains and operations. It offers supply chain opportunities that should not be overlooked. Whether revolutionary or evolutionary, 3D printing technology is recognized as an important trend that will significantly impact supply chains. The technology has the power to help companies significantly reduce costs, overcome geopolitical risks and tariffs, improve customer service, reduce the carbon footprint, and drive innovation for competitive advantage. It will lead to future changes in the structure and supply chain operation of businesses. The future of 3D printing in supply chain is bright. More information about 3D printing technology in the supply chain industry can be found in the books [14-16] and the following related journal: *The Asian Journal of Shipping and Logistics.*

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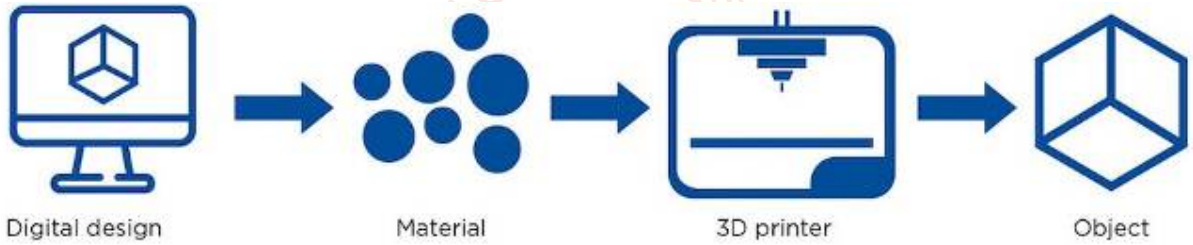


Figure 1 How 3D printer works [4].

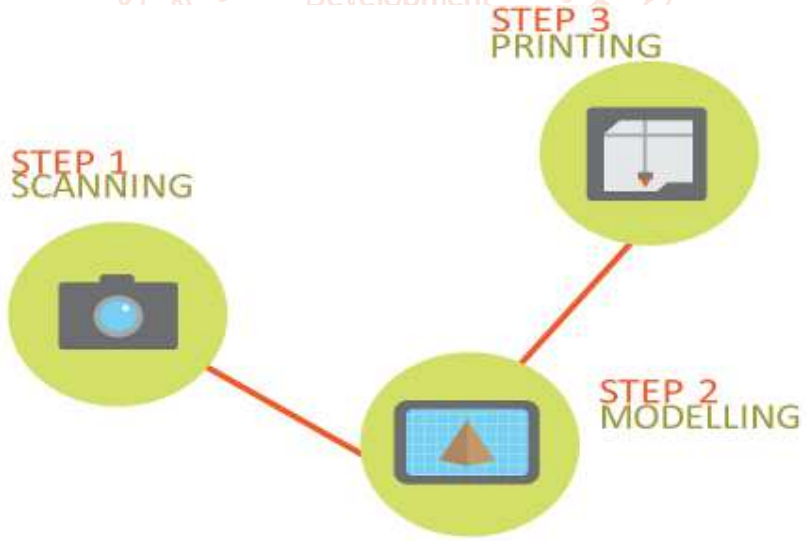
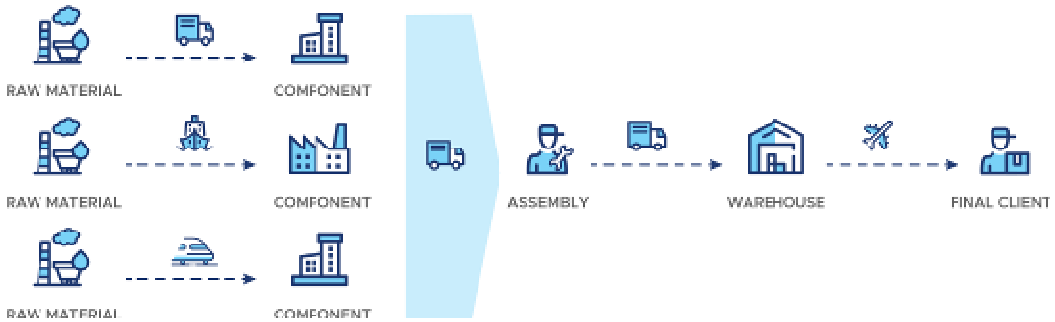


Figure 2 3D printing involves three steps [5].

Figure 3 A typical 3D printer [6].

Figure 4 A symbol of supply chain [7].



(a)

(b)

Figure 5 Comparing (a) traditional supply chain with, (b) 3D printing supply chain [8].

Figure 6 Supply chain 3D printing [9].

Figure 7 A soldier using 3D printer [10].

Figure 8 Nieka's molding facility [10].

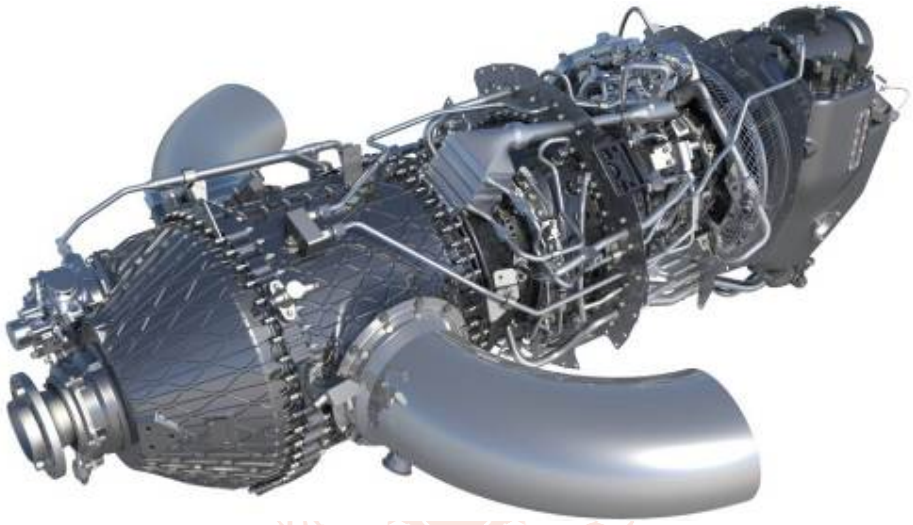


Figure 9 GE's 3D-printed airplane engine [8].

Figure 10 A DHL warehouse [11].

Figure 11 Some automotive parts [12].