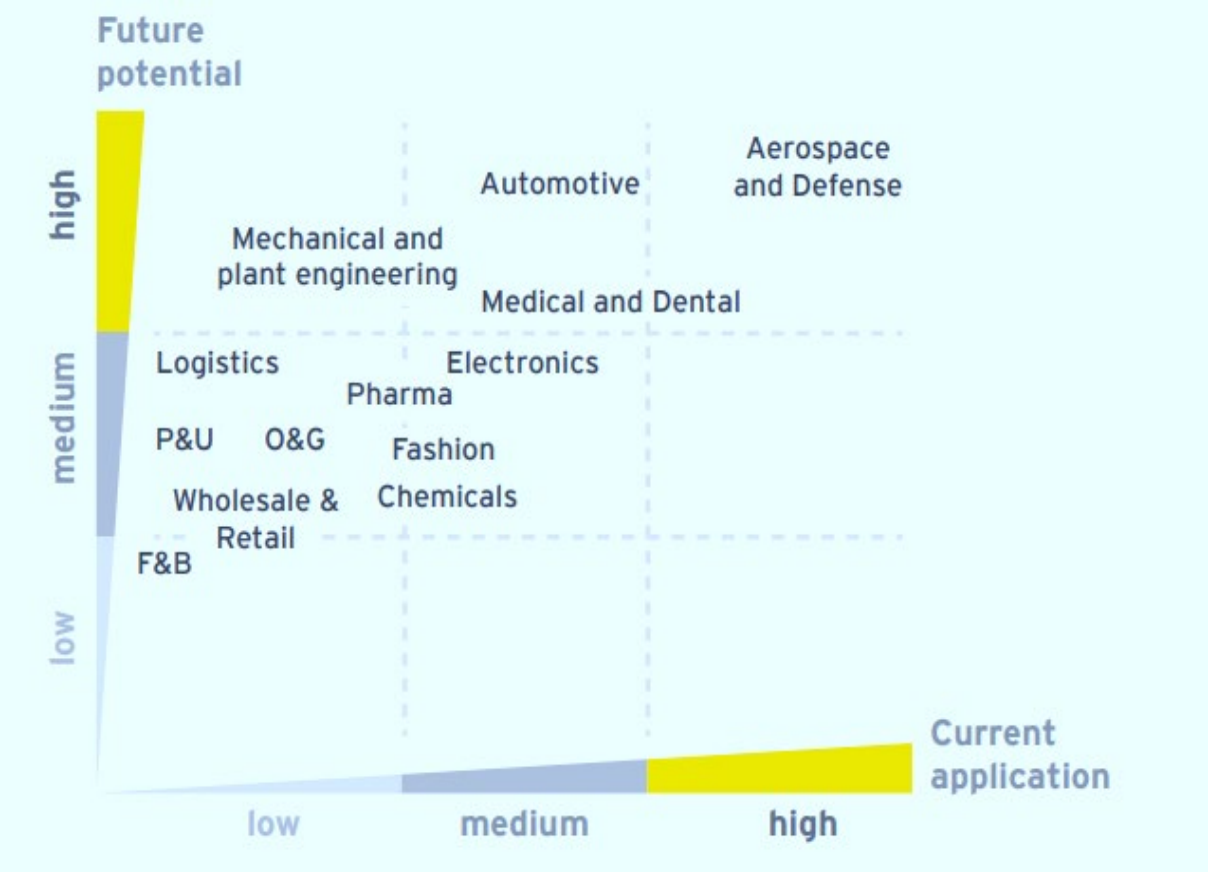

Figure 1. Present application and future prospective of AM by industry (Thewihsen et al., 2016)

Recently, AM has moved far beyond its basic prototyping applications only. Now it is an essential part in some organization's production lines (Marchese et al., 2015). 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. Figure 2 shows the possible benefits if AM in supply chain.

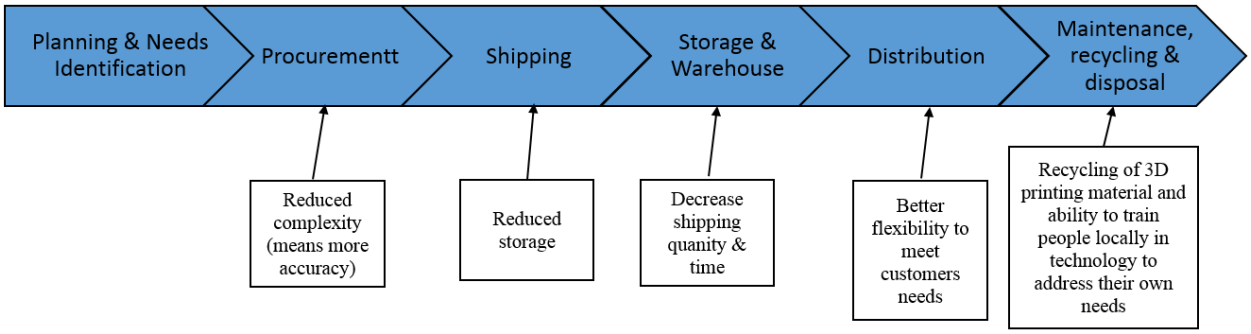

Figure 2. Typical Supply Chain with AM Augmentation (KT, 2018)

Therefore, in this research work, an overview of the benefits and changes that AM can be made in the supply chain are explained. Since, AM is becoming the new paradigm in the manufacturing, so it is better that the implication of this technology in supply chain to be realized. This research area is largely underdeveloped compared to other domains. Therefore, there it is important to focus in implementing AM within the supply chain to cope with the changes in industry and its requirements that are particularly concerned with industry 4.0 which have a positive impact of AM on supply chains and supply chain management.

2. AM for Supply Chain

A contemporary survey finds out that the supply chain's expenditure is more than 5 percent of the total cost of goods. The savings in total management of supply chain including transportation, and inventory carrying costs could be significant. To thrive in today's global market, organizations must find initiatives that would results into cost cutting specially in supply chain. One of the initiatives that prevails recently was the use of Radio Frequency Identification (RFID) in the supply chain that showed its several benefits (Attaran, 2007). In this decade AM, is emerged as a promising technology with numerous benefits in supply chain also.

In parallel with its effects on how the product is conceived and fabricated, AM has intense and extensive influence on the supply chains' actions, at the same time with a reconfiguration of the chain's configuration. This is predominantly significant for those supply chains where effectiveness, time, and service level are imperative; however simultaneously, AM can also provide a sharp reduction of supply chain costs (Pérès and Noyes, 2006, Tuck and Hague, 2006, Liu et al., 2014). Though, in spite of the technology potential, less than 10% of the AM literature explores its impacts on supply chains (Costabile et al., 2017). One of the major impacts of AM over supply chain dynamics originates from the possibility to fabricate parts/products in the vicinity of usage point, with a dispersed, instead of centralized, manufacturing network. AM requires only two essential elements to start manufacturing operations that are computer aided design (CAD) model of the part and an AM machine. Any stage on the supply chain that is connected to the web and equipped with an AM-based machine can be considered as a manufacturing site along the supply chain (Zanoni et al., 2019). In this way, commercial divisions and regional warehouses equipped with AM machines would also get involved in production processes. Some of the researchers have shown the direct benefits of AM in supply chain as shown below in figure 3.

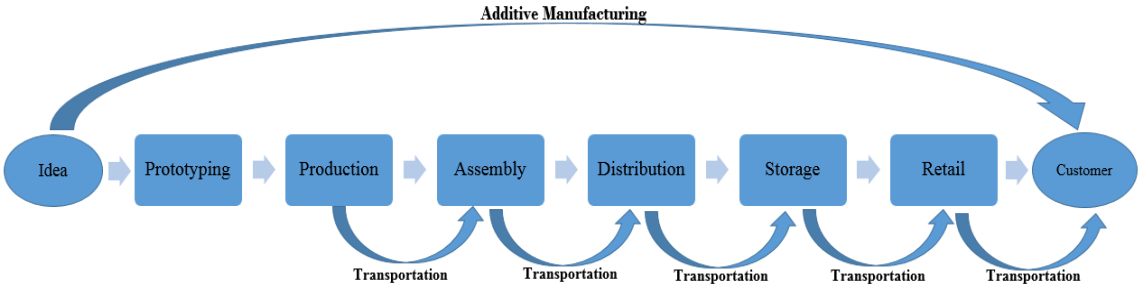

Figure 3. Direct benefits of AM in Supply Chain

However, it is not as simple as it is shown in figure 3. The figure only shows the outside view, since with the help of AM several stages of manufacturing and logistics can be skipped, so it will results into time and cost saving. Moreover, since AM is much more agile and flexible, the manufacturing is usually dispersed and near to the point of use, saving a greater part of logistics costs.

Holmström et al. (2010) evaluate how AM can empower decentralization of supply chains. In a decentralized supply chain, role of manufacturer can be prolonged to logistics providers as well. AM can enable both centralized and decentralized supply chain solutions and come up with cutbacks in logistics, inventory holding, and lead time. While an ultimate decision on the use of AM would be subject to numerous aspects, such as, part's volume, batch size, raw materials, and other cost evaluations, but for some particular segments such as spare parts, there are great capabilities that can be explored by applying additive technologies specifically for slow moving parts (Holmström and Gutowski, 2017). The removal of assembly and pre-assembly steps, and the potential to reduce the supplier base of the company have also been mentioned as benefit of AM. The technology has the potential to eradicate the need for both high volume production facilities and low-level assembly workers, thus significantly decreasing supply chain cost. Fabrication can take place practically anywhere at the same cost. Therefore, it is no longer economically proficient to transport goods moving through the world to get to the customer. The most noticeable influence of AM can be observed in supply chain functions of planning, design, sourcing, and logistics. Ramanan (2017) shows the impact of the AM on supply chain, as shown in figure 4.

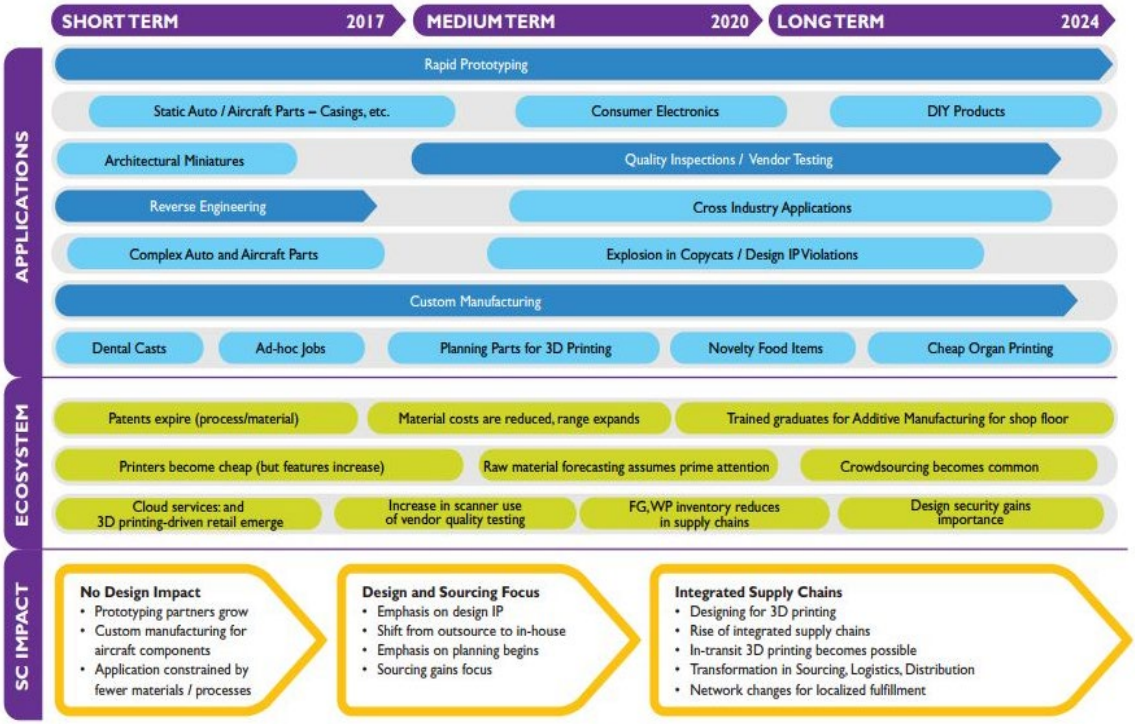

Figure 4. Effect of AM on Supply Chains

AM would cut high costs of inventory holding and logistics, and allows on-demand production of small batch sizes of highly customized goods in a cost-effective way. This is mainly resulting from increasing frequency of production runs and the consequential decrease in stock levels (Zanoni et al., 2019). Table 1 (Attaran, 2017) shows the impact of AM on supply chain.

Table 1. Impact of AM on Supply Chain

Key Factors	Benefits
Cost Savings	• Eliminate the need for large bulk inventory • Eliminate the need for high volume production facilities • Reduce transportation cost • Eliminate penalty for redesign • Reduce the size of an economical lot • More economical and effective packaging solutions • Vetting out designs: offer customized designs at lower cost • Reduce labor inputs: eliminate low level assembly workers • Reduce required tooling and machining centers • Economical mass customization
Speed Responsiveness	• Eliminate the time lag between design and product • Shorter lead time • Enabling on-demand manufacturing • Improving process flexibility • Supply chain disintermediation • Hedge against disruptions
Quality Improvement	• Reduce production waste • Improve quality • Incorporate customer feedback • More optimum products across many industries • Eliminate excess parts that cause drag and add weight • Management of demand uncertainty

Environmental Impact	• Improve sustainability • Less negative impact on environment • Reduce carbon footprint • Reduce the waste that accrue in traditional manufacturing

Table 2 shows the difference between conventional supply chain and AM influenced supply chain.

Table 2. Conventional Supply Chain vs. AM influenced Supply Chain

Conventional Supply Chain	AM Influenced Supply Chain
High transport costs	Lesser transportation cost
High level of required inventory	Decrease in required inventory
Long lead times	Shorter manufacturing lead time
Push supply chain	Pull supply chain
Complex distribution networks	Reduced inventory
Challenging management of demand uncertainty	Easier management of demand uncertainty
Using intermediaries in the global supply chains	Supply chain disintermediation
Dependency on economies of scale	Dependency on economies of scope
Lengthy response to customer demand	Quick response to customer demand
Manufacturing far away from point of use	Manufacturing closer to point of use
Supply chain disruptions-broken machines, regional turmoil, or shipping delays	Hedge against disruptions

For manufacturers, AM most useful role may turn out to be more in enhancing supply chain capabilities or innovating across whole sections of those supply chains than in creating new products. Still, a lot of work is required to design and operate a proper framework for supply chain for additive manufacturing.

3. Conclusions

AM has a great potential of product customization and can have extraordinary effects on production and delivery. By linking clients and get their inputs at the design and fabrication stages, will results into positive effect on each customer. AM has the ability to mitigate costs and increase revenues. Thus, supply chain can swiftly react to changes in the marketplace. In conclusions one can say that, AM has positive effect on supply chains in several ways, such as quicker product development, lesser economical lot size, better production flexibility, and mitigation in wastage of material. Early adopters of the technology can take the advantages from sourcing of materials to logistics and product distribution. Mass customization will become less expensive, and the supply chain will become more local, internationally connected, and more effective.

Acknowledgements

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