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(REVIEW ARTICLE)

Additive Manufacturing (3D printing) and the Future of Supply Chains: Opportunities, Challenges, and Trends

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Abstract

Additive manufacturing (AM), otherwise referred to as 3D printing, has rapidly grown and is considered a core element in the digitalization of supply chain management. It allows for localized and on-demand production, reducing dependence on central storages and mass manufacturing. AM is transforming how modern supply chains operate by enabling more flexible, localized, and sustainable production. The rapid evolution of AM has begun to reshape traditional supply chain models across multiple industries. By enabling localized, on-demand, and customized production, 3D printing challenges conventional approaches to sourcing, inventory management, and logistics. This review analysis current research and industrial applications to examine the transformative impact of 3D printing on supply chain design, efficiency, and sustainability. Key findings highlight that additive manufacturing can significantly reduce lead times, lower transportation and inventory costs, and enhance supply chain agility. Moreover, it supports sustainability goals by minimizing waste and carbon emissions through shorter, localized supply networks. It also discusses how AM helps organizations respond to disruptions while highlighting new risks, such as cybersecurity threats and quality control issues. By analyzing findings from academic sources, this review identifies both the opportunities and limitations of AM adoption. Overall, the literature shows that AM can make supply chains more agile, environmentally friendly, and resilient when combined with strong digital infrastructure and proper management practices. However, challenges remain in standardization, cost, and integration across industries.

Keywords: Additive manufacturing, 3D printing; Supply chain management; Inventory reduction; Sustainability

1 Introduction

Traditional supply chains often struggle with long lead times, high inventory levels, and dependency on distant suppliers, which limits their ability to react quickly to disruptions or fluctuating demand. These challenges increase costs and reduce operational flexibility, especially when sourcing specialized spare parts or dealing with global transportation delays [1,2]. Additive manufacturing, or 3D printing, is one of the most celebrated technologies that has disrupted supply chains in their design and management. After being confined to initial prototyping, today it is a basic production technology that enables local, on-demand production with a high degree of customization [3]. Unlike centralized production systems, AM enables companies to manufacture products close to their customers, which has resulted in lower costs, less waste, and faster delivery times [4]. This transformation has shaken up logistics, inventory management, and collaboration with suppliers. Even though technology brings flexibility and sustainability, it demands high digital infrastructure, strict quality control, and adherence to constantly changing regulatory standards [5].

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The rise of three-dimensional (3D) printing — or additive manufacturing (AM) offers a digital alternative that supports localized, on-demand production. This approach minimizes waste, reduces logistics complexity, and enables companies to manufacture components closer to their point of use, strengthening supply chain resilience [6]. From a procurement and sourcing perspective, AM changes how organizations plan purchasing strategies. Instead of relying heavily on long-distance suppliers and bulk orders, firms can now produce certain components internally or through local AM service providers. This shift requires procurement teams to reassess what to buy, how to manage digital assets, and which suppliers possess technological capabilities that support AM integration [7,8]. Understanding these changes is essential because 3D printing does not only alter production; it reshapes procurement priorities. Buyers must now evaluate factors such as material compatibility, data security, and digital file ownership in addition to traditional criteria like cost and delivery performance. As supply chains become more digital and decentralized, procurement's role expands from a transactional function to a strategic partner supporting innovation and sustainable operations [9]. AM has moved from rapid prototyping into functional manufacturing across industries, including aerospace, healthcare, automotive, and construction, over the last decade. This development has raised significant questions about supply chain management since AM alters where, how, and when parts can be produced. Early studies report AM's potential to reduce inventory, shorten lead times through local on-demand production, and simplify assembly by consolidating parts-all of which could reconfigure traditional supply chains [10,11].

The review draws on recent studies that examine how AM reduces reliance on global suppliers, shortens lead times, and enables on-demand production. It also discusses how AM helps organizations respond to disruptions while highlighting sustainability and environmental impact, and economic and strategic implications.

2 Impact of Additive Manufacturing on Supply Chain Management

Additive manufacturing has significantly changed how supply chains are designed and managed. By enabling on-demand and localized production, AM reduces the need for large-scale warehouses and long-distance transportation. This shift allows companies to bring production closer to consumers, cutting costs and reducing environmental impact. Research shows that AM helps companies simplify supply chains by reducing the number of suppliers and the number of intermediate steps required for production. This simplification makes supply chains leaner and easier to manage. AM also supports mass customization, allowing firms to quickly adapt products to customer needs without major changes in production processes. However, these benefits come with new challenges. Managing digital designs, ensuring data security, and maintaining consistent product quality are now critical concerns. Companies adopting AM must develop new supply chain strategies that combine traditional logistics expertise with advanced digital capabilities[12-15].

3 Strategic Redesign: Centralization vs. Decentralization

Additive manufacturing has significantly changed the structure of the supply chain by questioning the paradigm of centralized production. Traditional systems are based oneconomies of scale and large factories to achieve efficiency, but the distribution approach in AM locates production closer to the end consumer [3]. Thereby, it allowed shifting from the "make-to-stock" system to the "make-to-order" one, which enhanced flexibility and responsiveness and reduced costs related to transportation and keeping stock [4]. Decentralization has presented challenges that differ in the areas of coordination, quality assurance, and management of technology. Although centralized systems promote efficiency and standardization, the ability for customization and flexibility are basic principles of decentralization. Hybrid models, hence, seem to provide the necessary balance, as firms adopt them to combine global efficiency with local flexibility in contemporary times. [16,17]

Marta Rinaldi et al.[18] proposed a quantitative study for the SC performance evaluation, combining different SC structures with Additive and Traditional manufacturing technologies. A discrete event simulation model has been developed in order to reproduce the behavior of the players and test the sustainability of different supply chain configurations. The outcomes show some strong findings related to the AM adoption. In particular, AM allows to design a shorter SC, offering a great support for the supply chain performance and providing strong savings in the supply chain lead time. Moreover, the AM decentralized network offers the best solution in terms of holding stock, and in general, on supply chain costs. In addition, the combination of additive technology and decentralization confirms to be the most flexible solution, with a high performance on customer satisfaction. Figure 1 shows the traditional manufacturing solution, characterized by a centralized supply chain. Generally, a conventional spare parts SC is composed of a single Producer, which manages and controls the whole production. He supplies few centralized storage centers, which distribute the components to smaller warehouses located close to the final user. Moreover, a single supplier has been inserted, considering just the procurement process of the main raw material. Thus, a five-echelon supply network has been modelled, composed of a Supplier (S), an Original Equipment Manufacturer (OEM), two Regional Distribution Centers (RDC), eight Local Distribution Centers (LDC) and the Final customers (FC).

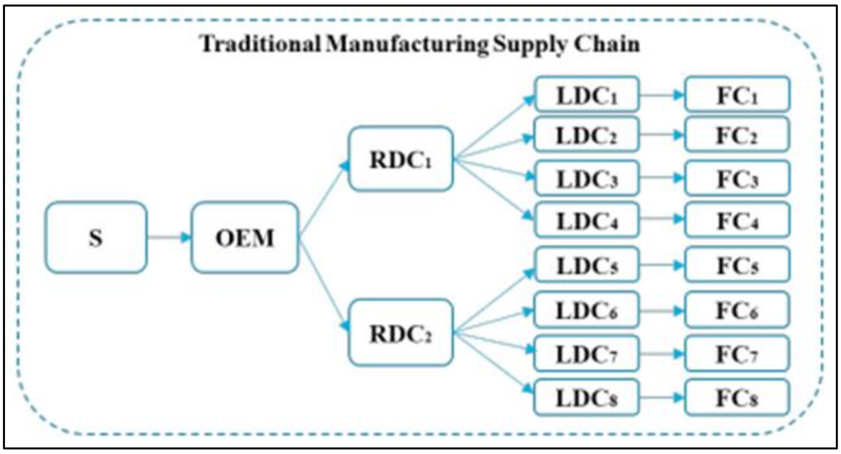

Figure 1 Traditional manufacturing structure[18]

As shown in Figure 2 the first scenario presents an AM supply chain with centralized structure. The idea is to consider a configuration similar to the previous scenario, in order to test the suitability of the solution just changing the production technology. Thus, the regional distribution centers become both Producers and they serve the small facilities, which face the end user. In the same way, the traditional OEM becomes the powder supplier. Finally, a four-echelon supply network has been implemented, considering one Supplier (S), two Original Equipment Manufacturers (OEM), eight Local Distribution Centers (LDC) and the Final customers (FC). Since AM technology well fits for small batches and promotes home fabrication, the second AM scenario adopts a highly decentralized structure. A three-echelon supply chain is considered with the local centers equipped to manage its proper production. In such case, the production stage is split and each OEM is located close to the final customer.

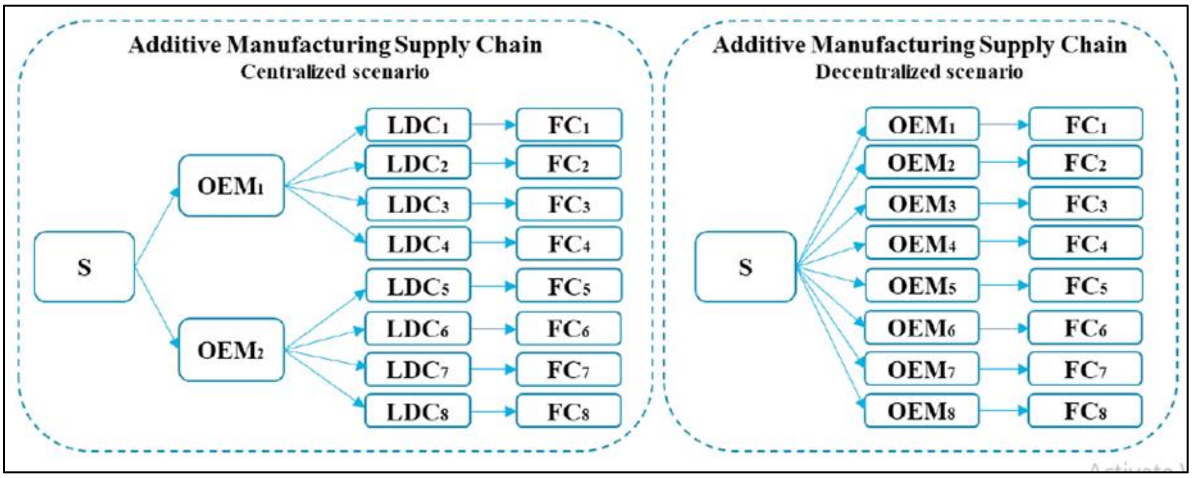

Figure 2 Additive manufacturing configuration with centralized and decentralized structure [18]

4 Supply Chain (SC) Reconfiguration

The use of additive techniques not only influences the customer's involvement in the design phase but offers the opportunity to have decentralized structures located close to the consumers. Therefore, based on their needs, the characteristics of the product offered and the market in which they supply, companies have the possibility of integrating additive technology in a centralized or decentralized way within their SC [19]. The use of AM in a centralized system implies the realization of the products in a central office and the subsequent shipment to the various distribution centers. Although this approach does not allow the reduction of transport times, it allows the aggregation of demand, coming from the various centers, so that the investment in the capacity of AM machines is used efficiently. The centralized approach is appropriate when the quantity demanded on the market is limited and lead time is not a critical factor. On the contrary, in distributed AM, production takes place in each distribution center, allowing the elimination of storage costs, the reduction of transport costs, and a faster response time. Barz et al. [20] conducted a computational study on the impact of additive manufacturing on transport costs. Their research showed that the introduction of technology and the new repositioning of production sites leads to a reduction in transport costs from a minimum of 43% to a maximum of 58%. In addition, making a few products in multiple factories allows for an SC that is less vulnerable to disasters and disruptions; the impact is no longer national or regional but localized in a single place of employment. In addition, decentralized production allows companies to explore the different markets in which the distribution/production centers are located, thus adapting production to these. However, its implementation requires high investments in 3D machines and specialized personnel justified only in case of high demand. Generally, the SC can be divided into three primary levels: upstream, midstream, and downstream. Upstream there are raw material and spare parts suppliers and manufacturers, midstream includes transport and warehousing processes, while downstream includes resellers and distribution of finished components to end customers. Between these levels it is possible to identify five types of flows that interconnect suppliers, producers, wholesalers, retailers, and consumers: product flows, process flows, information flows, financial flows, and energy and natural resources flow. Figure 3 shows a traditional SC, a centralized AM model, and a decentralized network reconfiguration model considering these flows. The SC in the conventional manufacturing setup includes several stakeholders from material suppliers and component suppliers to the final customers. In the centralized model, the AM machines are installed in centralized locations at the upstream levels. In particular, both original equipment manufacturers and spare parts suppliers use these. A hybrid approach is used: AM is not a substitute for traditional manufacturing but a complement [21]. Furthermore, there is a transfer of digital flows through the 3D CAD file that can reach the company through a global digital network. Centralized production allows integration with the e-commerce channel. Through the AM it is possible to implement production which allows customers to create their products and to transfer files in one place for manufacturing; this facilitates the relationship between the final customer and the organization without the need for intermediaries such as channel resellers. In the decentralized model, assuming that future technological improvements and the widespread use of AM will reduce the cost of these technologies, especially those for manufacturing metal parts, the machines are installed in distributed locations. This leads to shorter and less complex supply networks, fewer transport needs, and shorter delivery times. Decentralized production will lead in the extreme case to user production. This hypothetical model has the potential to significantly influence the SC. Consumers will no longer buy physical products from companies, only CAD files that will be self-produced using technologies located in their homes [22].

5 Logistics and Inventory Transformation

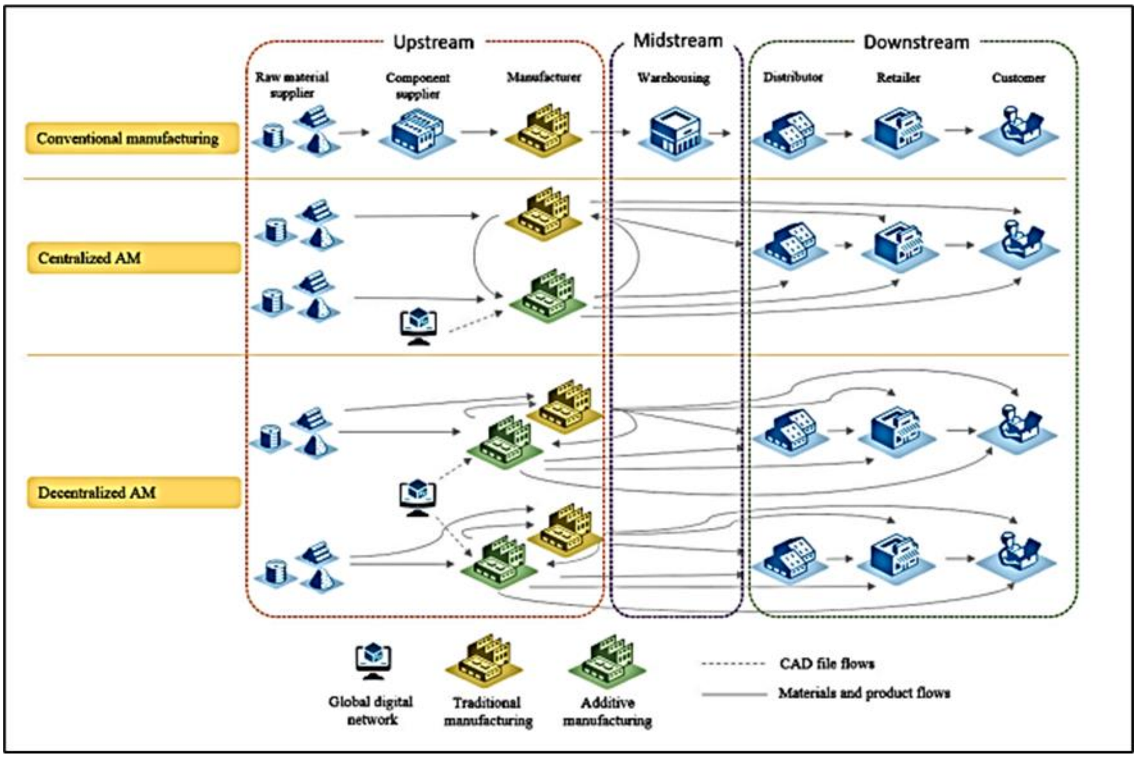

Figure 3 Supply Chain reconfiguration [17]

The Logistics and Inventory Management Department has had a large share of the radical change brought about by additive manufacturing technology. Instead of keeping a large inventory in warehouses, companies now rely on digital inventory, where designs are stored electronically and manufactured only when needed. This transformation led to significantly reduced storage costs and waste and reduced delivery times, which in turn contributed to increasing efficiency and competitiveness [3].

6 Impact of Additive Manufacturing on Inventory & Warehousing

The use of 3D printing in supply chain management has a direct impact on how inventory and warehousing are structured. Kubáč and Kodým [23] describe how AM shifts inventory from physical stock to digital files, allowing companies to store CAD models instead of large volumes of finished goods or spare parts. This digital-inventory approach reduces holding costs, eliminates product-obsolescence issues, and decreases the need for large storage facilities [24]. Westerweel et al.[25] highlight that this model isespecially valuable in industries where downtime is costly—such as aerospace, defense, and energy—because local printing of spare parts at remote locations minimizes lead time and maintains operational continuity. Companies no longer need to maintain extensive inventories of critical components; instead, they print only the number of units required when needed [26]. Talebi developed a multi-objective MILP model illustrating how incorporating AM nodes into supply networks significantly reduces total inventory levels, transportation costs, and carbon emissions [27]. These findings demonstrate that AM contributes not only to economic efficiency but also to environmental sustainability. Overall, additive manufacturing decentralizes production, enabling firms to shift from storage-based systems to on-demand production models [27,28]. With the ability to print items locally, companies depend less on large centralized warehouses and instead utilize flexible, smaller production hubs. This leads to shorter logistics routes, reduced material waste, and a more agile supply-chain structure. In this sense, AM transforms warehouses from storage centers into dynamic spaces for localized production and digital coordination [24].

7 Upstream and Organizational Integration Challenges

As additive manufacturing AM continues to transform logistics and inventory systems, it simultaneously presents complex challenges to upper supply chains, necessitating deeper and longer integration within organizations. The shift toward digital production is causing disruption in traditional supplier models, as the focus is shifting from manufacturers of traditional components to suppliers of raw materials and digital design solutions. This transformation highlights the paradigm shift, as explained by Ronke [29] emphasizing the importance of enhancing collaboration and information exchange between manufacturers and material suppliers to maintain product quality and safety, as well as tracking them during manufacturing through AM. When looking within organizations, there is an urgent need to restructure internal processes and align them with the workflow driven by additive manufacturing technologies. The research by Gustafson et al. [30] highlighted the pivotal importance of collaboration between and within different departments, especially between logistics, engineering, and information technology teams, to facilitate seamless integration and achieve the best and most remarkable results. However, challenges such as lack of digital expertise, varying operational practices, and cultural resistance often hinder progress in this field. Therefore, addressing these obstacles requires institutions to adopt a dual approach: enhancing technological infrastructure through strategic investments and cultural development that prioritizes cooperation and embraces digital transformation at all hierarchical levels.

8 Impact of Additive Manufacturing on Supply Chain Resilience

One of the major economic advantages of 3D printing is its contribution to enhancing supply chain resilience. Resilience refers to the ability of a supply chain to adapt, recover, and continue functioning during disruptions. Additive manufacturing enhances resilience by increasing flexibility, responsiveness, and self-sufficiency. Studies show that AM allows companies to quickly reproduce spare parts or components during crises, reducing downtime and dependency on global logistics. It also enables firms to reconfigure production lines rapidly in response to demand changes or supply interruptions. For example, during the COVID-19 pandemic, several industries used 3D printing to produce critical items such as medical equipment and spare parts when traditional suppliers could not meet demand. This explains the strong potential of AM in creating adaptive and responsive supply networks. Nevertheless, achieving resilience through AM requires careful planning. Firms need to build robust digital infrastructures, ensure knowledge sharing across supply partners, and maintain backup digital designs for key components[15,31,32].

9 Impact of Additive Manufacturing on Make-or-Buy Decisions

The adoption of 3D printing has reshaped traditional make-or-buy decisions by enabling firms to shift from external procurement to selective in-house production. Instead of relying entirely on suppliers for complex or customized parts, organizations can manufacture low-volume components internally, which reduces dependency on external vendors and increases operational flexibility [1]. This shift, however, introduces a new set of procurement priorities. Rather than purchasing only physical components, procurement teams must now source printing materials, digital design files, and maintenance services for AM equipment. These requirements add new decision variables such as printer capacity, material compatibility, data security, and design ownership—factors not typically considered in traditional purchasing models [7]. Research also suggests that while in-house production offers speed and customization benefits, it may not always be cost-effective for high-volume items. Organizations must carefully evaluate the total cost of ownership (TCO), including equipment investments, training, and quality control systems. This highlights a gap in the literature: many existing sourcing frameworks remain focused on cost and lead time, with limited consideration for digital risks such as file protection and cyber-security [6]. Overall, 3D printing expands the boundaries of make-or-buy decisions by requiring procurement professionals to balance technological capability, digital asset management, and strategic sourcing considerations. Effective decisions depend on a clear understanding of when internal manufacturing adds value and when external suppliers remain more efficient [33]. Figure 4 illustrates how additive manufacturing affects the Purchasing and Supply Management (PSM) process phases.

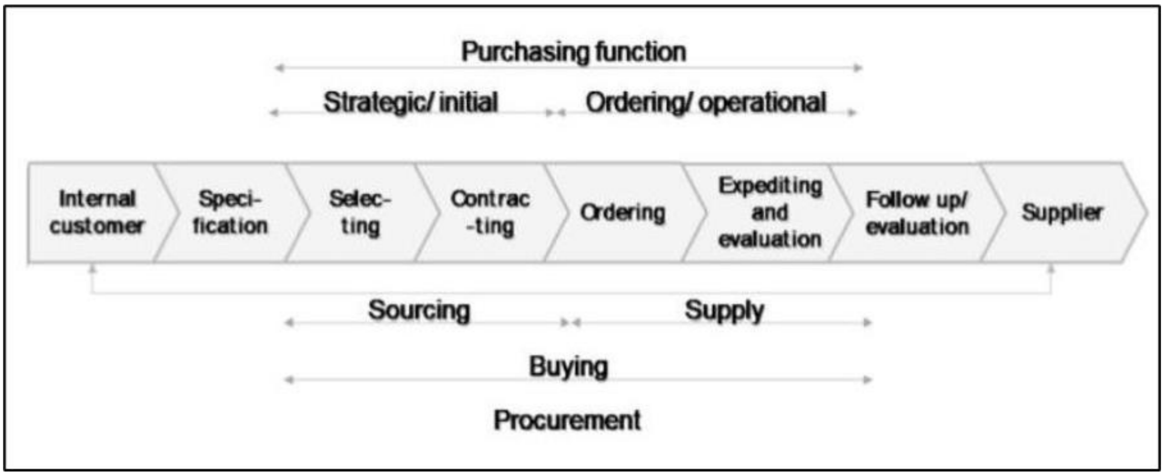

Figure 4 Effects on the Purchasing Supply Management (PSM)process phases

The model shows that AM has a noticeable impact on specification, selecting, contracting, and ordering activities. By simplifying product structures and reducing the number of required parts, AM minimizes sourcing complexity and allows organizations to rely on fewer but more specialized suppliers. This shift also changes the balance between sourcing and supply activities, as companies increasingly depend on AM service providers rather than traditional component manufacturers [34].

10 Supplier Selection and Relationship Management

The introduction of 3D printing has expanded supplier selection criteria beyond traditional measures such as cost, lead time, and delivery reliability. Procurement teams must now evaluate suppliers based on their technological readiness, AM material expertise, digital design compatibility, and capability to secure sensitive files shared across platforms [22].A key change is the shift from transactional purchasing to collaborative partnerships. Many AM suppliers provide not only materials but also design services, printing capacity, and file optimization. This makes the relationship more integrated, requiring closer communication and shared responsibility for product performance [9].

Another challenge in supplier selection is the lack of standardized quality benchmarks for AM components. Variations in printer calibration, operator skill, and material batches can lead to inconsistent output between suppliers. Procurement teams therefore need new assessment tools that measure process stability and material certification, but the literature shows limited frameworks for this type of evaluation [33]. Overall, 3D printing transforms supplier relationships into strategic alliances that require both technical alignment and digital trust. Despite these benefits, existing research underestimates the governance structures needed to manage data-sharing risks, long-term co-design partnerships, and accountability for product quality across decentralized AM suppliers [1].

11 Logistics and Inventory Implications

One of the most widely recognized benefits of 3D printing in the supply chain is the reduction in inventory levels and transportation requirements. Because products can be printed locally and on demand, companies can store digital designs instead of physical stock [6]. This change allows procurement to manage fewer bulk orders and focus on material availability for printing instead of large-scale component delivery. Gebhardt et al.[35] found that additive manufacturing can shorten lead times by up to 70%, as it eliminates the need for complex multi-tier supplier networks. For procurement and sourcing, this means more direct communication with fewer suppliers and less reliance on international shipping or customs procedures. Moreover, the possibility of decentralized production reduces the risks of supply chain disruptions such as geopolitical conflicts or transportation delays.

12 Challenges and Risks in Procurement and Sourcing

Even though 3D printing offers many benefits, bringing it into procurement and sourcing comes with some real challenges. One of the biggest concerns is protecting intellectual property. The digital files shared between companies and suppliers can be copied or changed without permission, which can cause legal and ethical problems [36,37]. Because of this, procurement teams need to have strong data protection agreements in place and choose suppliers who take cybersecurity seriously.

Another challenge is making sure the products meet quality standards. Unlike traditional manufacturing, the results of 3D printing can vary depending on the type of printer, its settings, and the skill of the operator. This makes it harder for procurement teams to guarantee consistent quality across different suppliers [33]. On top of that, the availability and cost of printing materials, like powders, polymers, and metals, can affect how flexible sourcing can be. Lastly, procurement professionals need to learn new skills and use digital tools, such as supplier databases for additive manufacturing, digital part catalogs, and online sourcing platforms. As industry keeps changing, procurement teams have to find the right balance between trying new innovations and managing risks to make sure supply remains reliable.

13 Sustainability and Environmental Impact

The complexities of modern supply chain integration are closely linked to broader challenges related to sustainability and resilience. Additive manufacturing offers significant opportunities for addressing such issues by focusing on waste reduction, emission reduction, and facilitating distributed production methods. This approach to distributed production enhances supply chain resilience by enabling the continuation of operations even in the event of a global logistical disruption [17]. This capability not only contributes to improving operational efficiency but also aligns with broader environmental and social goals. On a macroeconomic level, additive manufacturing is driving a significant shift in global trade dynamics and industrial competitiveness. The increasing shift toward local production is leading to a transformation in value creation away from traditional manufacturing centers toward local economies supported by digitization. However, realizing the full potential of these innovations requires international cooperation, the establishment of regulatory standards, and the creation of comprehensive digital infrastructure. These steps are essential to ensure transparency, maintain quality standards, and provide equitable access to technological advancement. [38]

13.1 Material Efficiency and Waste Reduction:

One of the strongest sustainability concepts is lean which means reducing the waste and the most benefit of 3D printing is its potential for reduced material waste. Traditional manufacturing in most cases relies on subtractive processes such as cutting or milling, which take away material from a bigger block to achieve the product. In contrast, additive manufacturing builds parts layer by layer, using only the amount of material required. Such a process can considerably reduce raw material consumption and waste generation [39]. For example, in aerospace, titanium parts machined conventionally can result in the waste of up to 90% of the original material, while 3D printing reduces waste to less than 10%. Such gains not only save materials but also reduce emissions related to extraction and processing. Still, researchers say that not all AM technologies are created equal. For instance, some processes rely on energy-intensive material preparation, such as powder or filament production, which may erase some of the environmental gains [40].

13.2 Circular Economy and Recycled Materials:

Another important contribution that 3D printing makes toward sustainability involves harmony with the concept of a circular economy. In conventional manufacturing, when a product has reached the end of its life, it is mostly sent to landfills and become waste. On the other hand, additive manufacturing enables the collection and reuse of materials through recyclable materials of polymers and their composites. For instance, biodegradable materials such as PLA (polylactic acid) and waste plastics like rPET can be used as printing filaments. Waste can be turned back into raw material [41] Researchers are also working on closed-loop systems whereby waste or defective prints are ground and reprocessed into new printing materials. These loops can significantly reduce both the environmental footprint and the cost of materials. Innovations in the recycling of metals and composites, are opening up sustainability possibilities for AM beyond plastics. However, attaining consistent quality and safety with the feedstock from recycled materials is still a technical barrier to wider industrial-scale use [42].

13.3 Localized Production and Supply Chain Decarbonization

From a supply chain perspective, 3D printing contributes to decarbonization by shortening transportation routes and enabling localized production. Rather than manufacturing products in large centralized factories overseas, companies can print products or spare parts closer to the places of application. This reduces not just the carbon emissions from global shipping, but energy use associated with storage, packaging, and warehousing. For instance, Kohtala [43] and Ford and Despeisse [10] point out that the localized additive manufacturing of goods can drastically reduce greenhouse gas emissions, particularly in automotive and consumer goods. However, these benefits are contingent on energy sources being used for printing. In this regard, if the process is powered by renewable energy, then the environmental gains are amplified; on the contrary, total emissions will remain high when it is based on fossil-based electricity.

13.4 Standardization and Life Cycle Assessment (LCA) Gaps:

While many studies showcase AM's sustainability benefits, there has yet to be a standard framework through which its environmental performance is measured. Recent analyses-including the State of sustainability assessments of metal AM study-present evidence that LCA method still differ in their scope and assumptions, therefore making results incomparable across different studies .Whereas some include raw material excavation to end-of-life disposal, others only measure energy consumption during printing. Such inconsistency leads to conflicting conclusions about whether 3D printing is inherently greener than traditional manufacturing [44]. The gaps identified here call for the development of standardized LCA protocols specifically for AM processes and materials. In addition, future studies should consider combining economic and environmental indicators to assess trade-offs between cost efficiency and sustainability performance.

14 Impact of Additive Manufacturing on Risk Management

Additive manufacturing also plays a critical role in risk management. Traditional supply chains are highly exposed to external risks such as supplier failure, material shortages, or transportation delays. AM helps mitigate these risks by decentralizing production and allowing manufacturers to operate smaller, distributed production hubs. By reducing reliance on a single supplier or location, AM lowers the impact of supply chain disruptions. Additionally, it improves transparency and traceability, as digital designs can be monitored and controlled through secure systems. However, the shift toward digital manufacturing introduces new types of risks. Cybersecurity threats, such as design theft or data tampering, have become major concerns. Moreover, quality assurance remains a challenge, especially when multiple decentralized facilities produce parts. Therefore, effective risk management in AM requires strong digital protection measures and standardized quality controls [13,45,46].

15 Economic Viability and Business Model Innovation

15.1 Cost Structures and Production Flexibility:

3D printing changes how companies manage production costs and economies of scale. Unlike traditional manufacturing, where economies of scale decrease the cost per unit for large quantities, additive manufacturing keeps the cost per part rather stable over a wide range of volumes as shown in figure (5).

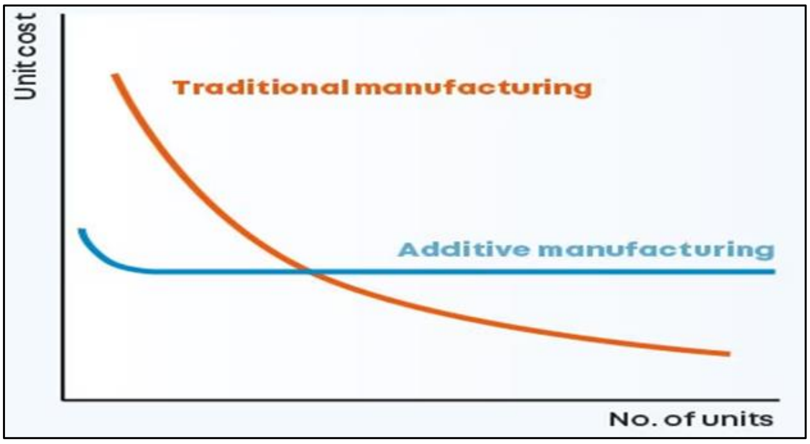

Figure 5 The trend of the cost function with the units produced [17]

This makes it very attractive for low-volume or customized production, particularly in those industries requiring high precision or frequent design changes, such as the aerospace, healthcare, and automotive industries [17]. By dispensing with molds, dies, and other forms of fixed tooling, 3D printing reduces setup times and eliminates many indirect costs as shown in figure *(6)*. Research suggests that it enables cost-effective on-demand production and spare parts for the firm to quickly meet changing customer needs without inventory. However, additive manufacturing involves high material and machine costs that may offset the economic benefits of mass production. For this reason, companies often adopt hybrid strategies, using AM for small-batch, high-value components and conventional methods for larger-scale production [17,47,48].

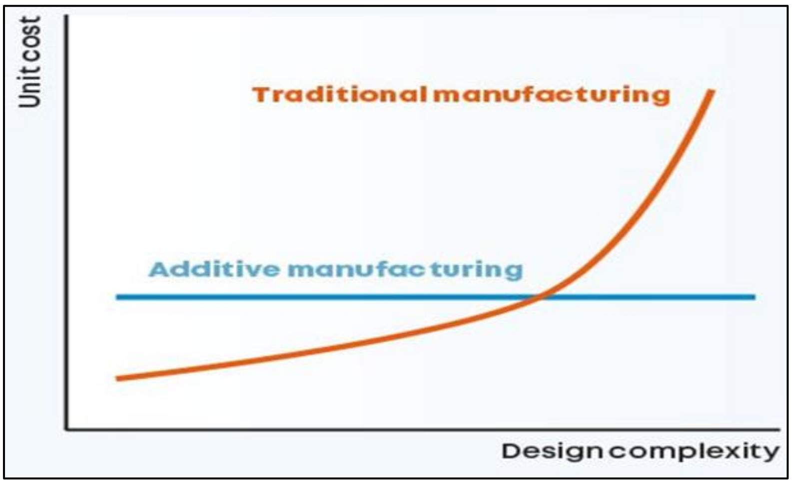

Figure 6 The trend of the cost function with geometric complexity [17]

16 Opportunities and Challenges in Additive Manufacturing and Future Directions

AM presents significant opportunities for enhancing sustainability in various industrial domains. A major advantage of AM is its material use efficiency [49]. Unlike traditional subtractive manufacturing methods that frequently result in considerable material wastage. Furthermore, AM holds the potential for energy saving advantages [50]. It tends to be more energy- efficient compared to conventional manufacturing processes, particularly in the fabrication of complex or lightweight components. AM contributes to environmental sustainability by streamlining supply chain dynamics [51]. Traditional manufacturing methods often involve extensive, globalized supply chains, which are significant sources of carbon emissions.AM, however, facilitates localized production strategies, thereby reducing transportation needs and the emissions associated with them. Moreover, AM has a significant role in advancing circular economy (CE) concepts. By facilitating the repair, refurbishment, or remanufacturing of components, AM can prolong the life of products, reducing the demand for new raw materials and decreasing waste generation. This method not only saves resources but also meets the increasing consumer and regulatory expectations for more sustainable, CE-oriented business practices [52]. In addition, the digital aspect of AM is in line with the broader transition to industry 4.0. It enables enhanced integration of digital technologies in manufacturing processes, improving efficiency and promoting more sustainable production methods. Figure 7 shows the key opportunities in AM [42].

While AM offers strong advantages, its widespread adoption faces several barriers. High initial investment costs, limited material availability, and the need for skilled operators are key challenges. Additionally, standardization and certification remain underdeveloped, making it difficult to ensure consistent product quality across different AM systems. Figure 8 provides an overview of the current challenges in AM industrial practices [42].

Future research should focus on integrating AM with other digital technologies like artificial intelligence (AI) and blockchain to improve coordination, security, and performance across supply networks. Governments and industries should also work together to develop global

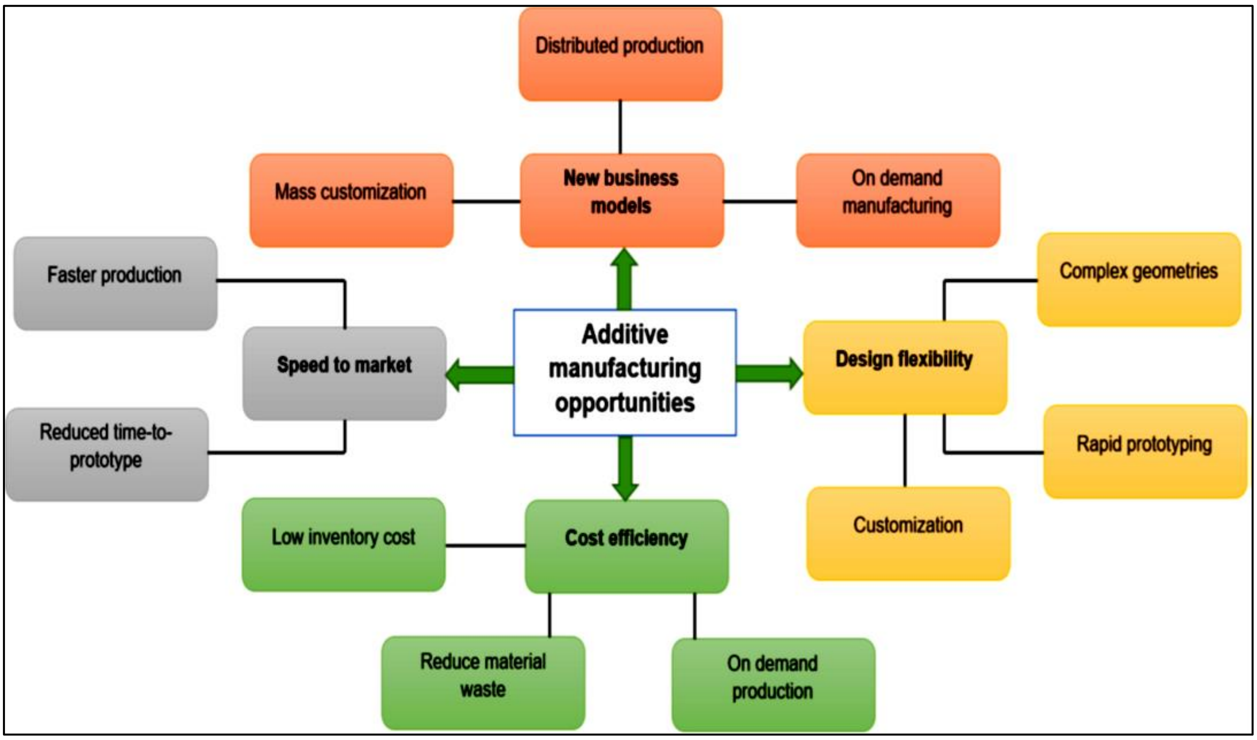

Figure 7 Strategic benefits of additive manufacturing (AM) [42]

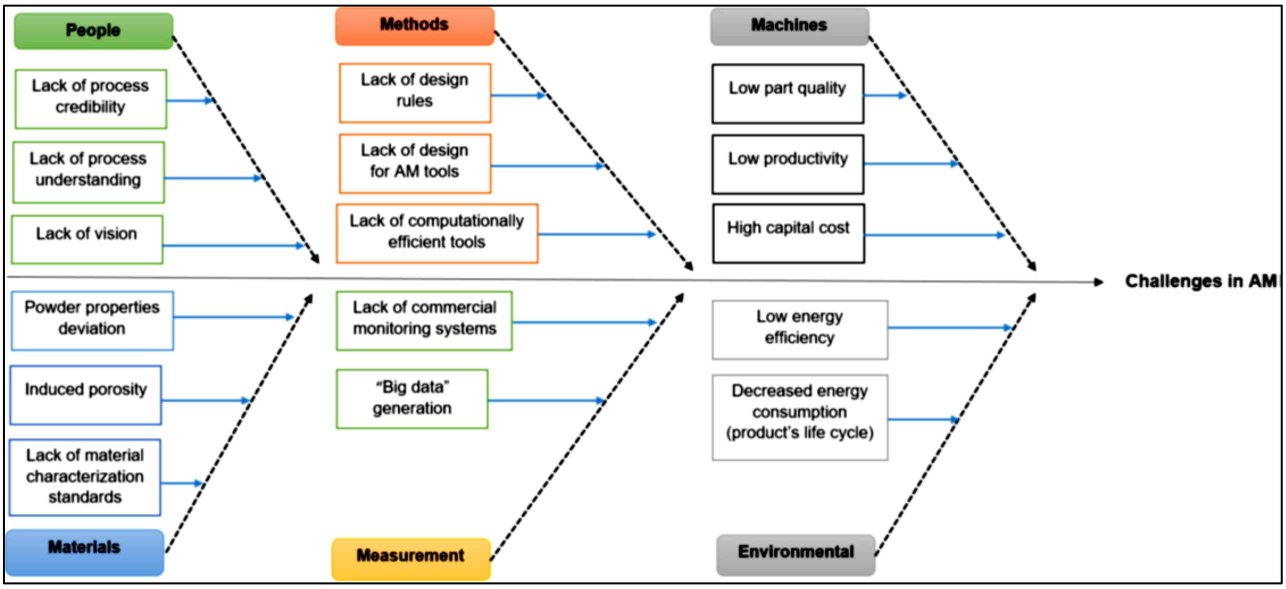

Figure 8 Challenges in industrial applications of additive manufacturing (AM)[42]

standards for AM-based production to ensure reliability and trust in international markets[13,46]. Additive manufacturing (AM) continues to evolve and will play a larger role in shaping future supply chains. As companies move toward digital and decentralized production, AM is expected to integrate more closely with technologies such as artificial intelligence (AI), blockchain, and the Internet of Things (IoT). These integrations will help improve visibility, automation, and coordination across global supply networks. At the same time, several gaps remain. There is still a need for stronger cybersecurity systems, consistent quality standards, and better training for workers. More research is also needed to understand the long-term economic and environmental impacts of AM. Overall, the future of AM in supply chain management depends on how well organizations can balance innovation with security, standardization, and sustainability [15,31]

17 Conclusion

Analysis of the scientific literature shows that additive manufacturing AM , also known as 3D printing, constitutes a fundamental shift in contemporary supply chain management. Its role was initially limited to prototyping techniques, but it has evolved to become a strategic performance that reshapes production, logistics, and distribution frameworks. By enabling decentralized production, encouraging on-demand manufacturing, and facilitating digital integration, this redefines the global value creation structure while enhancing operational efficiency. The integration of 3D printing into supply chain management marks a major transformation in how organizations design, manufacture, and deliver products. From a procurement and sourcing perspective, this technology is not only about improving efficiency, it redefines purchasing activities and supplier relationships. The reviewed literature shows that additive manufacturing shifts procurement from a traditional transactional function to a more strategic and technology-driven role.

3D printing enables companies to produce parts on demand, reduce reliance on external suppliers, and move production closer to customers. These advantages help shorten lead times, lower inventory costs, and support sustainability through localized production and reduced waste. For procurement, decisions now depend on digital design access, material compatibility, and supplier technological capability rather than only price and quantity. However, adopting 3D printing also brings new challenges. Procurement teams must manage data security, intellectual property, and quality in a digital environment. Therefore, supplier evaluation frameworks should include digital collaboration and sustainability performance. Overall, procurement and sourcing departments are becoming key drivers of innovation in digital manufacturing. By developing new skills, forming strategic partnerships, and aligning sourcing strategies with sustainability goals, procurement can lead the shift toward smarter and more resilient supply chain. While 3D printing offers many benefits, it has difficult challenges, such as limited resources, expensive equipment, and lack of skill. However, innovation is still ongoing and training can help address these difficult obstacles over time.

In conclusion, additive manufacturing is more than a new production technique. It is a strategic tool supports the creation of stronger, smarter, and more sustainable supply chains capable of facing future global challenges.

Compliance with ethical standards

Disclosure of conflict of interest

No conflict of interest to be disclosed.

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