Gradus Vol 12, No 1 (2025)
ISSN 2064-8014

THE IMPACT OF ADDITIVE MANUFACTURING TECHNOLOGIES IN THE FUTURE DEVELOPMENT OF SUPPLY CHAINS

Loránd Csaba Császár 0009-0009-2437-2574 [1*] *Krisztián Bóna* 0000-0001-9662-6259 [2]

Department of Material Handling and Logistics Systems, Faculty of Transport and Vehicle Engineering, Budapest University of Technology and Economics
https://doi.org/10.47833/2025.1.ENG.008

Keywords:
supply-chain; additive; resilience; resistance; vulnerability

Article history:
Received 05 February 2025
Revised 25 February 2025
Accepted 12 March 2025

Abstract
The study encompasses multiple industrial sectors, with a particular focus on those where additive technologies can be effectively implemented. The most vulnerable element of the production process is the production line equipment employed in serial production, where the interdependent and continuous sequential processes are highly vulnerable to a potential failure on the production line. The availability of parts for complex production line equipment, often from other continents, is very limited at the point of end-use, so that the failure of even a single component can cause a complete shutdown of production and gigantic losses. However, the integration of an additive manufacturing tool within the maintenance department of the respective plants could offer a viable solution in such circumstances. The present study investigates the impact of additive manufacturing technologies on the development of supply chains. The large-scale industrial implementation of additive manufacturing technologies should be approached in a manner analogous to the integration of surgical robots in the medical field: while experiments are underway, their widespread utilization remains impractical, either from a financial or technological standpoint.

1 Introduction

The supply chain can be defined as the logistical network encompassing the procurement of raw materials and the delivery of finished products to final consumers. It encompasses manufacturing, transportation, warehousing, distribution, and all other activities essential for the delivery of products and services to the market. Supply chains are characterized by their considerable size and intricate interdependency, rendering them particularly vulnerable. The disruption of a single link in the chain can have a cascading effect, affecting all subsequent processes. The following section outlines the primary challenges associated with supply chains:

- Inventory management
- Supply disruptions
- Cost and price volatility
- Sustainability challenges

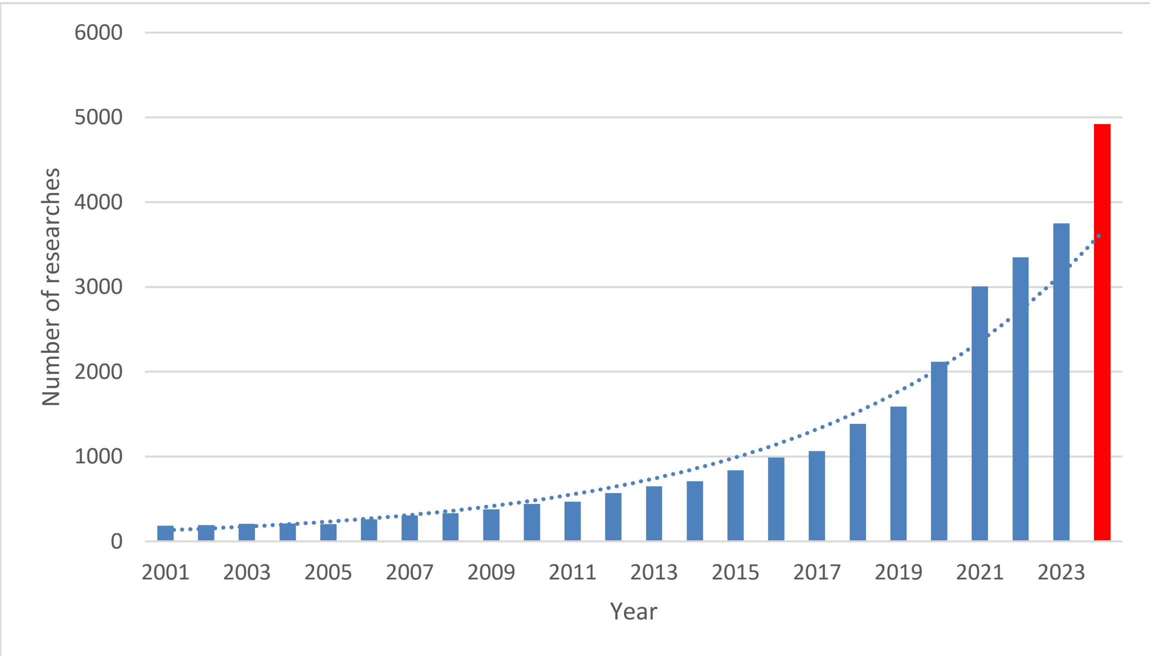
* Corresponding author: Loránd Csaba Császár
E-mail address: csaszar.lorand@edu.bme.hu

The issues previously referenced must be addressed by care systems. The ability of the system to manage these challenges is contingent upon the inherent resilience of the supply chain. In the context of supply chains, resilience is defined as the capacity to withstand and defend against external influences, while resilience is defined as the ability to recover from a problem that has already occurred. The present study investigates the impact of additive technologies on the resilience and resilience of supply chains.

2 Method

The initial phase of the research was devoted to a comprehensive review of state-of-the-art. The fact-finding phase of the research work can essentially be interpreted as a preparatory operation. The objective of this process is to identify a perspective that has not been extensively examined within the field. It is during this exploratory phase that the research team will determine the approaches to be taken and the lines of enquiry to be pursued in addressing the impact of additive manufacturing technologies.

The investigation of the state-of-the-art was based on articles from various scientific journals. The resultant findings were summarized in an effort to determine the number of articles relating to the interconnection of additive manufacturing technologies and supply chains. To summarize the articles, an aggregation chart (1. Figure) was created, which arranged the articles according to the year of publication and the keywords mentioned above.



1. Figure: The number of research activities in the project scope

As illustrated in the lower part of 1. Figure, there has been a substantial increase in the number of studies and research papers examining the relationship between additive manufacturing technologies and supply chains. [1] The red bar on the right-hand side of the bar chart indicates the projected number of publications for the year 2024, which is estimated to approach 5,000 articles on this subject. It is important to note that these results are highly forward-looking, as the significance and timeliness of the topic is further emphasized by these figures. A methodology was formulated for the classification of publications. [2] The proposed procedure is not only subjectively based on differing opinions from person to person, but also more objective, comparing all research with all publications and thus establishing a priority order. [3] For the purposes of this evening's discussion, I have applied the COMBI method, a decision support formula that exhibits the aforementioned properties. The COMBI method is distinguished by its ability to process quantifiable data while producing more reliable results.

The COMBI method was utilized to identify publications that would be examined in greater detail. The primary focus of this investigation was the results obtained, the extent to which they were covered, and the conclusions and implications that the authors drew at the conclusion of their respective publications.

3 Results

3.1 Main outcomes from the investigation of state-of-the-art

The outcomes of the examined publications exhibited variability, attributable to the diverse approaches adopted in addressing the subject.[8] However, there was unanimous consensus among the authors that additive manufacturing could not substitute for mass production machinery, as the production time and cost of the products was excessively high, and the process would not be profitable. Nevertheless, there are other areas where additive manufacturing technologies have great potential. Specifically, its integration into production processes could enhance efficiency by reducing defects and prioritizing maintenance. Conversely, in industries where high-volume production is not financially viable, the product range is extensive and demand is subject to fluctuations in all respects, the utilization of additive manufacturing technologies is also justifiable. An illustrative example of this is the spare parts supply segment of the automotive industry.[6] [9]

3.2 The application of additive technologies within the domain of logistics

Additive technologies are assuming an increasingly significant role within the logistics sector, with the capacity to enhance efficiency, reduce expenditure and accelerate processes across a wide range of domains. The following areas are illustrative examples of the present application of this novel technology.[4]

3.2.1 Manufacture of parts and spare parts

Additive manufacturing facilitates the expeditious and cost-effective production of spare parts or special components for transport or warehousing systems by logistics companies. This method is especially advantageous when a company requires components that are no longer available in the commercial marketplace, or when expeditious provision is imperative to address fluctuating demand. [5]

3.2.2 Personalized packaging

The advent of 3D printing technology has profoundly impacted the logistics sector, particularly in the realm of packaging. This technological advancement has enabled logistics companies to create customized packaging solutions that are optimized to fit the specific characteristics of products, thereby reducing transportation expenses and enhancing product safety. This personalized packaging is of particular importance when transporting goods that are delicate or valuable.

3.2.3 Development of warehousing systems

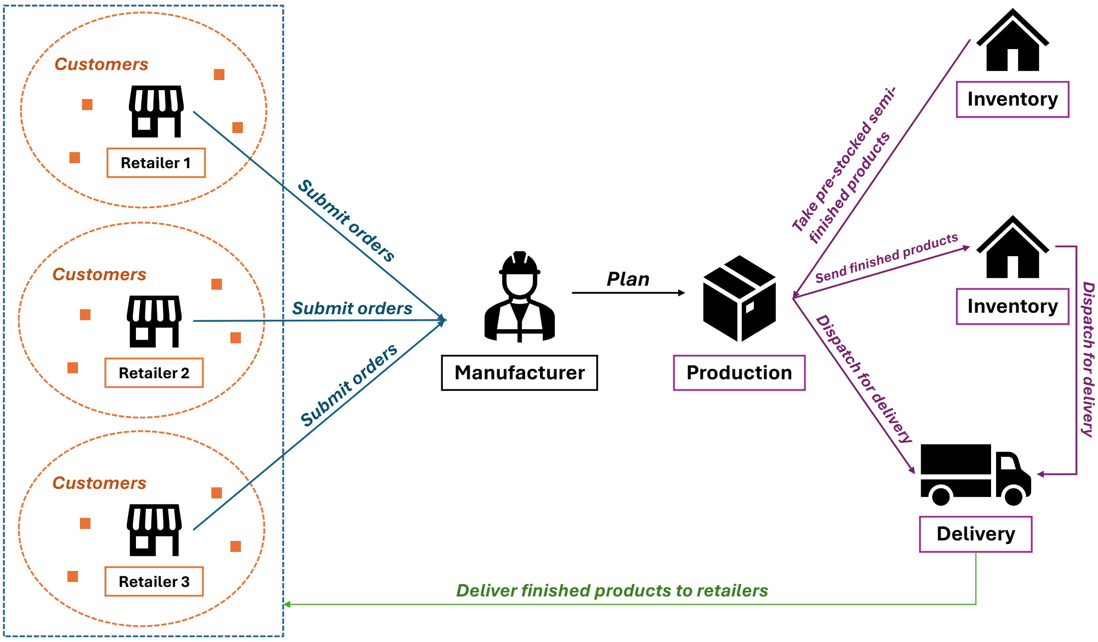
Additive technologies have the capacity to facilitate the producing of specific warehouse devices. To illustrate this point, consider the production of components for automated storage systems (AS/RS) or warehouse robots. The utilization of 3D printing in such contexts has been demonstrated to facilitate enhanced efficiency, reduced production time, and cost optimization.

3.2.4 Parts of transport equipment and vehicles

The application of additive technology by logistics companies has enabled the expeditious fabrication of components for various forms of transport equipment, including loaders and forklifts, as well as transport vehicles. In the last time, this approach has started to replace the conventional manufacturing methodologies, which have been characterized by protracted timelines.

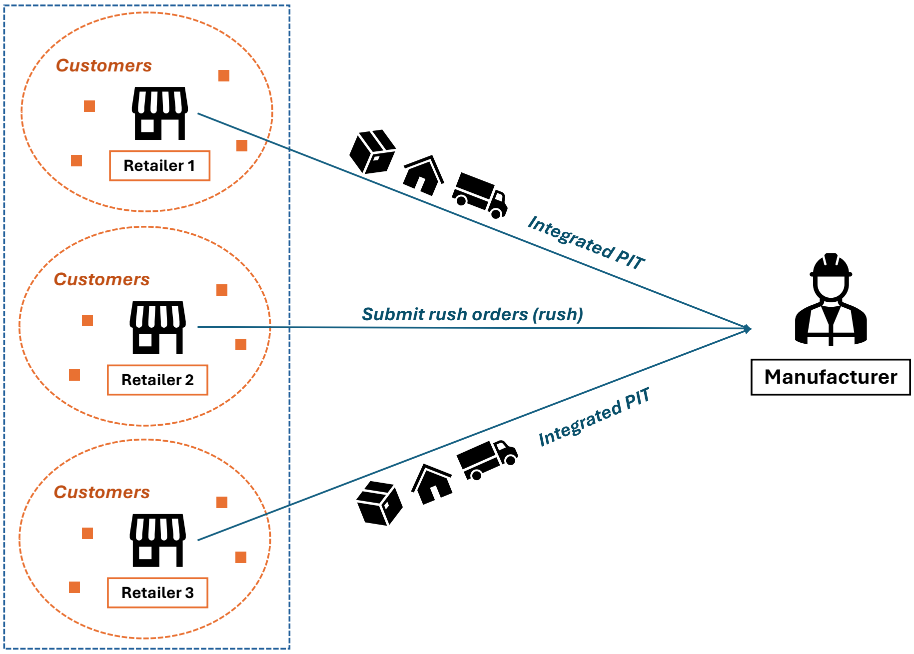
3.2.5 Optimization of logistics networks

Additive technologies have the capacity to assist logistics companies in the expeditious production of sample models and prototypes, which can facilitate the design and optimization of logistics networks. The establishment of 3D print shops facilitates the production of a more extensive range of smaller series. The operation of such facilities can be characterized by their substantial numbers and decentralized structure, resulting in a more distributed production model.



2. Figure: Supply chain structure in the traditional production network [3]

Figure 2 illustrates the typical topology of a conventional logistics networks nowadays, while figure 3 forecasts the new structure of the network supported by additive technology. It is very conspicuous that the structure will be clearer and simpler as in the conventional case, but it is important to emphasize that in the new structure new challenges must be identified and solved in the future.



3. Figure: Supply chain design in additive manufacturing supported production [3]

Moreover, it is evident that the supply chain topology facilitated by additive technologies is characterized by enhanced streamlining. The reduction in the number of participants involved is indicative of a more integrated system, with these the members of the chain assuming a greater number of tasks.

3.2.6 Innovative transport solutions

The advent of 3D printing has engendered a paradigm shift in the domain of transportation, opening the way for the development of innovative solutions and equipment. This technological advancement has the potential to usher in a new era of bespoke, lightweight, and robust transport structures that promise to enhance operational efficiency, reduce expenditure, and expedite transportation processes.

3.2.7 Sustainability and waste reduction

Additive technologies enable logistics companies to utilize a reduced quantity of material by printing only the amount required, thereby minimizing unnecessary waste. Furthermore, the potential for local production can decrease the necessity for transportation, thereby reducing environmental impacts.

4 Future possibilities in the detailed analysis

In the following discussion, some of the options will be highlighted that has been described in the results of investigation of state-of-the-art and which have the greatest potential in the future.

4.1 Effects on performance of supply chains

In the context of the automotive industry, additive processes find greater application in group or workshop allocation, with particular relevance to the supply of spare parts. This aspect is of equal importance to the manufacturing activities of car manufacturers themselves. The automotive industry is obligated to ensure the supply of spare parts in a timely and uninterrupted manner, due to both high demand and regional and EU legislation. Additive manufacturing technologies, such as 3D printing, are particularly relevant for the supply of spare parts to the automotive industry, where there is a high demand for unique, small quantities of parts. The demand for such parts is often subject to variation, and it is not always economically viable to produce or stock large quantities, particularly for components that are less frequently used and for older models. The adoption of additive manufacturing enables the production of parts to be tailored to individual orders, thereby reducing inventory costs and delivery times. This approach fosters greater flexibility by enabling rapid responses to specific needs, thereby ensuring that customers receive the necessary spare parts in a timely and cost-effective manner. This approach also benefits sustainability by reducing unnecessary production and waste, and optimizing inventory management. It would be very important to estimate the performance in various time- and quantity-based indicators the difference between the conventional and the additive manufacturing supported systems. In order to do this, specific simulation models must be developed fitted to specific use cases. In this way hypothetical potential can be discovered, and the possible gaps for future developments can be identified.

4.2 Effects on resilience and resistance of supply chains

The advent of additive manufacturing technologies has been demonstrated to enhance the resilience of supply chains by facilitating a more expeditious response to disruptions and fluctuations in demand. Technology facilitates expeditious substitution of parts and products, mitigates inventory management risks, and fosters local manufacturing, thereby diminishing the repercussions of global supply issues. Moreover, the flexibility afforded by additive manufacturing to production processes enables supply chains to adapt to market conditions and to recover from turbulence with greater alacrity. To measure the resilience and resistance is not a matter of course. There are not any exact general numerical indicators because the specific cases request specific indicators. In the future, it would be very useful to define some indicators specialized to the additive manufacturing supported chains to estimate in an exact way the hypothesized increase. [7][10]

These indicators can be integrated into the above-mentioned simulation models, and in this way with several numbers of numerical experiments the impacts will be investigated and identified.

5 Summary

Additive manufacturing technology has been demonstrated to make a significant contribution to improving the resilience and robustness of supply chains. This is achieved by enabling rapid adaptation to disruptions and reducing global supply risks. Technology facilitates the local production of spare parts, ensuring the swift restoration of operational systems and the mitigation of associated expenses and periods of inactivity. This is of particular importance in cases where long-term production downtime or supply chain disruptions render the sourcing of parts a challenging endeavor. The capacity for agile and prompt response to change is a key advantage of the aforementioned technology. The planned future study will build on this research by developing scenarios for both of the options outlined in the detailed analysis part and building models to demonstrate the viability of additive technologies in supply chain operations.

References

[1] Abdel-Aal, A. B.-M. (2023). Towards supply chain resilience with additive manufacturing: A bibliometric survey. Supply Chain Analytics, Volume 2. doi:https://doi.org/10.1016/j.sca.2023.100014

[2] Carvalho, B. N.-H. (2022). The implications of additive manufacturing technology adoption for supply chain resilience: A systematic search and review. *International Journal of Production Economics*, Volume 247. doi:https://doi.org/10.1016/j.ijpe.2021.108387

[3] Dababneh, W. C.-Y.-L.-F. (2021. 12). Additive manufacturing-enabled supply chain: Modeling and case studies on local, integrated production-inventory-transportation structure. *Additive Manufacturing*, Volume 48, Part B. doi:https://doi.org/10.1016/j.addma.2021.102471

[4] Ficzere, P. (2021). EFFECT OF 3D PRINTING DIRECTION ON MANUFACTURING COSTS OF AUTOMOTIVE PARTS. *Ijtte*, 94-101. doi:10.7708/ijtte.2021.11(1).05

[5] Kónya G., Ficzere P. (2024). The Effect of Layer Thickness and Orientation of 3D Printed Workpieces, on The Micro- and Macrogeometric properties of Turned PartsActa Polytechnica Hungarica, 21. doi: 10.12700/APH.21.2.2024.2.13

[6] Gutema, T. L.-H.-E. (2024). Impacts of Adopting Additive Manufacturing Process on Supply Chain: Systematic Literature Review. *Logistics*, 8. doi: https://doi.org/10.3390/logistics8010003

[7] Kumar, S. G.-S.-S.-A.-A. (2022). Examining the influence of big data analytics and additive manufacturing on supply chain risk control and resilience: An empirical study. *Computers & Industrial Engineering*, Volume 172, Part A. doi:https://doi.org/10.1016/j.cie.2022.108629

[8] Mercurio, F. C.-V. (2023). An overview of the impact of additive manufacturing on supply chain, reshoring, and sustainability. Volume 7. doi:https://doi.org/10.1016/j.clscn.2023.100103

[9] Péter, J. Á.-F. (2019). Additív gyártástechnológiák szerepe a veterán gépjárművek alkatrészellátásában. *MATARKA*, 38-41. doi:2929976

[10] Yuvaraj, J. B.-M.-M. (2023). Improving agility and resilience of automotive spares supply chain: The additive manufacturing enabled truck model. *Socio-Economic Planning Sciences*, Volume 85. doi:https://doi.org/10.1016/j.seps.2022.101401