ADDITIVE MANUFACTURING TECHNOLOGIES ADOPTION IN AUTOMOTIVE SUPPLY CHAINS – THE THEORETICAL REVIEW

Mia Delić
University of Zagreb, Faculty of Economics and Business, Croatia
E-mail: mdelic@efzg.hr

Blaženka Knežević
University of Zagreb, Faculty of Economics and Business, Croatia
E-mail: bknezevic@efzg.hr

Petra Škrobot
University of Zagreb, Faculty of Economics and Business, Croatia
E-mail: pskrobot@efzg.hr

Abstract

In a highly competitive environment, manufacturers are looking for ways to shorten supply chains in order to eliminate shipping costs and shorten production cycles. Enabling the production of individually customized products, which was impossible until now, additive manufacturing technologies caused the revolution in product development and the supply chain structures in various industries. There are two areas in which the additive manufacturing technologies have the greatest impact on the competition in the automotive supply chain: (1) as a source of product innovation, and (2) as a driver of supply chain restructuring. Regarding issues related to the scope of additive manufacturing technologies adoption in supply chains, previous studies were mainly based on an examination of the technical characteristics and advantages of using additive manufacturing technologies. By reviewing and the analysis of scientific and technical literature, available published research results and respecting the paper objectives and the purpose, this paper will explore the impact of additive manufacturing technologies adoption in the automotive supply chain. Specifically, the paper aims to explore the influence of additive manufacturing technologies adoption on lean and agile concepts of supply chain management in the automotive industry.

Key words: additive manufacturing technologies, supply chain management, automotive industry, automotive supply chain

1. INTRODUCTION

The development of additive manufacturing technologies and their adoption in the production processes started to affect the supply chain management in manufacturing sectors of many industries, including the automotive industry (Reeves, 2013). The use of additive manufacturing technologies has the potential to reduce the phases of the traditional supply chains; production can be moved closer to the final customer, and the net effect would be shortening of the supply chain due to reduction in the storing large amounts of finished products. Then, increasing competition strengthens the pressure to reduce the time-to-market - in this context the automotive industry can derive great benefits from the additive manufacturing technologies adoption in the production processes.

The automotive industry accepted the mass production as a standard production strategy (Zhang & Chen, 2006, p. 668). Traditional mass production relies on the ability of companies to accurately predict demand, which in turn affects the decisions on operations and production. However, with the changing demands of the final customers and the transition to mass customization, production based on forecasts may no longer be able to cope with the rapid market changes (Zhang & Chen, 2006, p. 668). Pires and Cardoza (2007) point out that todays` manufacturers are faced with the following challenges: strong pressures to reduce cost and delivery times; improving the quality and overall customer service and the production of environmentally friendly products; a significant reduction in product life cycle and the rapid introduction of new products, with strong pressure to reduce the time-to-market and cost of product development; pressure on the supply of new markets; strengthening and intensifying communication channels in the supply chain. This means that automotive producers need to be flexible and respond to customer requirements in order to succeed in the modern market.

Previous studies determined the importance of efficient supply chain management, but not in the context of the additive manufacturing technologies adoption. One explanation of this research gap is the perception among researchers that the additive manufacturing technologies are not ready for the commercial application yet. In order to define how the additive manufacturing technologies adoption in production processes affect the company's business in the modern competitive environment, it is necessary to observe the problem in a broader context of the supply chain. Therefore, it can be concluded that the study of the impact of additive manufacturing technologies adoption in the context of supply chain is timely and feasible.

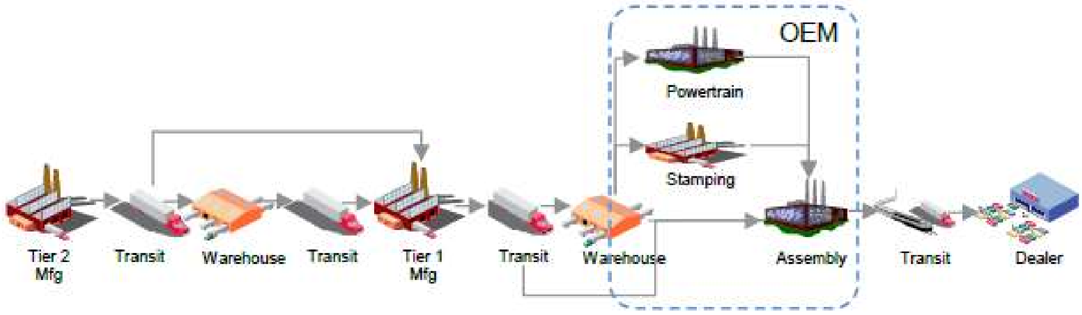
This paper will analyze the current scope of additive manufacturing technologies adoption in the automotive supply chain context, in order to meet the requirements of customers. More precisely, the paper aims to explore the influence of additive manufacturing technologies adoption on lean and agile concepts of supply chain management in the automotive industry. Also, the current challenges and perspectives of additive manufacturing technologies adoption in the automotive supply chain will be defined.

2. SUPPLY CHAIN MANAGEMENT IN THE MOTOR VEHICLE INDUSTRY

In a complex automotive supply chain, companies established a tiered supply chain based on degrees, in order to reduce the number of companies directly associated with original equipment manufacturers and their assembly plants. By following this type of supply chain management more responsibility is forced upon the first level of suppliers that can be more easily and effectively managed (Vonderembse & Dobrzykowski, 2013, p. 3). A typical automotive supply chain includes product components suppliers (levels 1-3), original automobile manufacturers (OEM), distributers and retail representatives (dealers). Geographical dispersion of suppliers also has an influence on the time necessary to deliver the parts (it differentiates form supplier to supplier). The hierarchical network of suppliers can be divided into three levels (Leškova & Kovačova, 2012, p. 97):

- Tier-one suppliers – manufacturers with their own facilities for production or assembly plants, near to the original equipment manufacturers (OEM), involved in product development and process innovation;
- Tier-two suppliers – manufacturers with their own production facilities, producing for tier-one suppliers;
- Tier-three or Sub-tier suppliers – raw materials manufacturers with their own production facilities for simpler product components, corresponding to the requirements of tier-two suppliers.

Figure 1. Automotive supply chain structure



Source: Thomas, K. (2012). *The Automotive Supply Chain in the New Normal: Analysis of the Industry and Its Supply Chain Opportunities* [available at: http://blog.jda.com/automotive-resurgence/ access November 28, 2015]

Automotive supply chain consists of Tier-two suppliers, Tier-one suppliers, production facilities (OEM) and retail representatives or dealerships (Figure 1). OEM production facilities are divided into assembly, powertrain and stamping department.

Original equipment manufacturers (OEM) are operating in a strong, complex environment with uncertain global competition. This has an effect on a constant necessity for a cost reduction, production increase and quality improvement at all levels of the supply chain. Therefore, the automotive supply chain turns form the forecast-based production, which results with high levels of stock, to demand-based production in order to respond to real time demands of final users. The priority in a supply chain and the original equipment production network is time-to-market reduction, with higher level of product personalization, efficiency and flexibility of assembly plants. In order to achieve this, OEMs are trying to reduce the number of direct suppliers involved in final product development. Supplier reduction is considered to be a strategic goal manly because of two reasons (Holweg, 2008, p. 26): (1) in order to develop long term relationships (Japanese style), motor vehicle manufacturers are focusing on a few key suppliers; (2) due to increase in the product variations, motor vehicle manufacturers must rely on their suppliers.

One of the key roles in automotive supply chain belongs to retail representatives (dealers) as original equipment manufacturer representatives and directly responsible for a product sale. The key factor in Lean supply chain is the retailers' optimal level of stock. Therefore, retailers must have an adequate combination of stocks in order to sale the vehicles from stock. For example, Toyota's sales model is designed so that the high percentage of sale is achieved with relatively low level of suppliers stocks; their goal is to storage 20 percent of all motor vehicle combinations representing 80 percent of sale from a specific market (Iyer et al., 2009, p. 15). One of the retailers' techniques to achieve this goal is to advertise and promote only the models available on stock.

With the rise in business relationship complexity in 21st century, supply chain management represents the new source of competitive advantage (Chopra & Sodhi, 2004; Kopczak & Johnson, 2003; Lee, 2004; Li et al., 2005). Despite the fact that the automotive industry was indeed the main source of strategic thinking in business development and supply chain management in the last century (Murray & Sako, 1999, p. 1), from the use of conveyor belt or development of Lean production principles there have been barely few initiatives lately, such as build-to-order production. It is inevitable to conclude that production process complexity in motor vehicle industry was merely an excuse not to accept innovations.

Because of the product complexity itself, most of automotive OEMs outsource the activities of product design or production and assembly of certain parts to specific suppliers. By concentrating the production of high-tech components to a few market leading suppliers, the original motor vehicle manufacturers are trying to simplify internal process management in the production facilities in order to maximize the cost reduction. Increased product technology complexity, great research and development expenses and constant innovations motivate the suppliers to sell entire design and products circuits, not just certain product parts. While the original motor vehicle manufacturers concentrate on developing the core capabilities that enable the necessary differentiation against the competition. According to Gobetto (2014, p. 7), the relationship models between OEMs and their suppliers are structured into different strategic profiles based on the macro-industrial needs:

a) German model in which local suppliers manage the research and development (R&D) activities, emphasizing the innovation appliance among German automobile manufacturers (for example, strategic innovation alliance between Bosch and Mercedes);
b) Japanese model in which the OEM represents the first level of innovations and serves as a supply chain support by connecting the suppliers through capital investments (for example, the relationship between Toyota and their supplier Denso);
c) American model which is commercially more open and oriented towards maximizing economic results in a short term, OEMs are concentrating on market leading suppliers which are taking part in product system development.

While the competition is growing rapidly, the pressure to implement a modular supply system is also increasing, mostly from the OEMs who are seeking more ways to maintain and increase competitive advantage within already overcrowded sector with unstable demand (Collins et al., 1997, p. 498). Carliss et al. (1997, p. 84) describe modularity as a process of developing a complex product combining smaller subsystems that can be independently designed and function together as a whole. In that context, car can be divided into seven main modules (Gneiting & Sommer-Dittrich, 2008, P. 105): (1) frontend module, (2) engine module, (3) greenhouse front, (4) greenhouse rear, (5) rear module, (6) exterior and (7) exhaust module. All these elements should be defined in the final customer order and then connected during the final assembly (Gneiting & Sommer-Dittrich, 2008, p. 105). Advantages created by using this type of approach are smaller number of direct suppliers, lower cost for the OEMs and lower investment risks. On the other hand the advantages for the modular suppliers are increased responsibility, involvement in the development and design of processes and products and the possibility of achieving higher share in activities that create value (Doran, 2004, p. 103).

One of the main reasons why the original motor vehicle manufacturers are transferring to the modular design is a reduced complexity of a final product. This overall approach will not only decrease the costs and complexity of production but also the time needed to develop new products.

Demand for highly differentiated vehicles production combined with the need for increased capacity exploitation, in order to satisfy the market needs, represent the leading drivers of production systems flexibility and product design that allows late configuration. Anyway, upcoming innovations in the field of automotive industry will lead to additional changes in relationship between suppliers and OEMs. In doing so, effective and efficient supply chain will become crucial for the manufacturers and their suppliers.

3. ADDITIVE MANUFACTURING TECHNOLOGIES ADOPTION IN THE AUTOMOTIVE SUPPLY CHAIN

Automobile industry accepted mass production as a standard production strategy (Zhang & Chen, 2006, p. 668). Traditional mass production largely relies on the company’s ability to accurately predict demand which has an effect on decision making in business and production. However, with changing customer demand and transition to mass customization, forecast-based production may not be able to cope with the quick market changes anymore. According to Kotler Marketing Group (2009), the original equipment manufacturers are obliged to improve production`s style and quality, increase organizational efficiency and import innovative characteristics into their products in order to attract final customers and expand to new markets.

As leaders in modern production development, automotive manufacturers have always been at the top of production technology development. They are also one of the first additive manufacturing technologies adopters, ever since first quick prototype production technologies like Stereolitography hit the market. Contemporary automotive manufacturers use high-tech tools such as Computer Aided Design (CAD) as well as simulation software that reduce production cost with constant improvements in the final product quality. Demands regarding product standardization in automobile industry have become so high that traditional approaches are no longer sufficient. Therefore, the automotive industry had to seek for new advanced and flexible technologies and innovations with Lean characteristics. The key in flexible automotive production strategies is digital engineering adoption including the additive manufacturing technologies.

OEMs work with thousands of different component suppliers and therefore are constantly discovering new ways to shorten the supply chain. With the use of additive manufacturing technologies, original equipment manufacturers are able to rely on internal capabilities and intense cooperation with tier-one suppliers and therefore to maintain or increase research and development share in creating values and production with no need for a complex supply chain management.

Additive manufacturing technologies are shown to be extremely useful to the engineers in product development, the commercial and cargo vehicle production and especially in the production of sport race vehicles with high performances. To this day, additive manufacturing technologies are mostly used in prototyping. However, today`s use of additive manufacturing technologies in automobile industry is present in a much significant proportion than just in developing complex onetime prototypes, which are still very important in automobile industry. Additive manufacturing technology advanced applications are more in use in today`s production processes, from production of certain parts to final assembly.

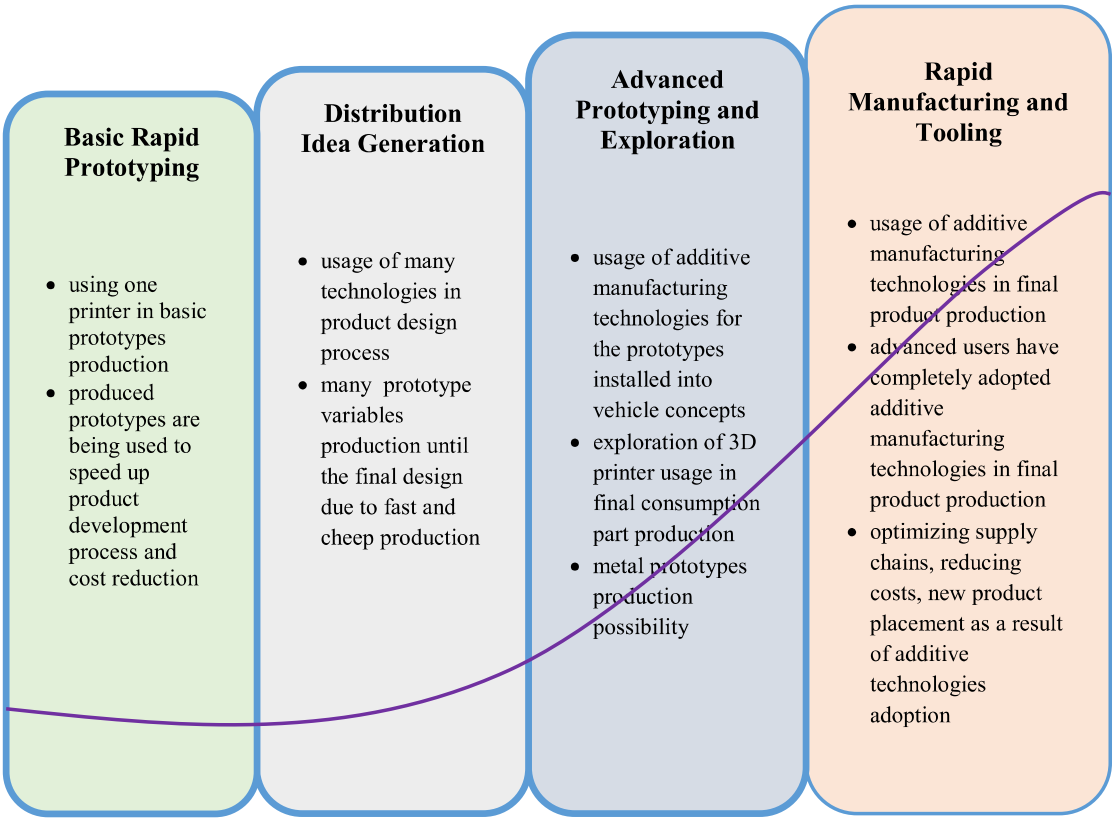
In a Great Britain automotive industry, the use of additive manufacturing technologies is mainly focused on the final product production, prototyping and tooling for high class moto-industry (Feloy et al., 2013, p. 4). Decrease in implementation costs throughout the last ten years has been the key reason for the use of additive manufacturing technologies among commercial vehicle manufacturer`s. Also, with significant production process improvement, such as quick CNC technologies, additive manufacturing technologies evolved from fast prototype production technology to fast production technology. Considering new characteristics and possibilities of additive manufacturing technologies, leading automotive OEMs are showing more interest in this field.

General Electric`s global research center develops techniques for the production of lightweight structures with additive manufacturing technologies for metal materials, that current manufacturing processes are not possible to produce (GE Works, 2012). Also, Carbon3D American start-up form California, started to produce polymer parts for BMW Group and Ford and is already announcing the production in large series (up to 50 000 pieces per year) with the use of additive manufacturing technologies in the near future.

Gobetto (2014, p. 24) indicated the main additive manufacturing technologies processes used in a production of certain mechanical parts as well as in assembly of operational systems, bodies and finished vehicles: (1) Thin laminated steel and aluminum parts printing by using the process of shearing machining, printing and assembly in a press machine; (2) Printing plastic parts by injection printing, injection compression, extruding and the process of coating and joining parts. These technological areas are linked to all supply chain stages and require specific product design investments from all the supply chain members, not only OEMs as it is usually predicted.

Figure 2 shows the additive manufacturing technologies adoption development model in automotive industry context (SmarTech Markets Publishing, 2015). In the first phase, companies used 3D printers to produce specific prototypes. A large portion of motor vehicle manufacturers entered the first phase of additive manufacturing technologies adoption ten years ago and some remained there until today. Alternatively, users in this phase very often used services of specialized companies for 3D prototype printing.

Figure 2. Development model of additive manufacturing technologies adoption in the automotive industry



Source: adapted from SmarTech Markets Publishing (2015). Additive Automotive: Advancing 3D Printing Adoption in the Automotive Industry [available at: https://www.smartechpublishing.com/reports/additive-manufacturing-opportunities-in-the-automotive-industry-a-ten-year access December 12, 2015]

In the second phase, users have expanded additive manufacturing technologies fleet in order to expand the prototype production activities on the production of final parts which cannot be produced by other production methods. In this phase, users are adopting greater 3D technology printing capacities in designing new parts, manual prototype production and the final product processing. In the third phase of additive manufacturing technologies adoption, companies use their own 3D printers and other forms of additive manufacturing technologies for functional prototypes production that will be installed into vehicle model concepts. Besides using 3D printing technologies to optimize product development and design, users apply additive manufacturing technologies in other business production areas (for maintenance and repair, tooling). Final phase of additive manufacturing technologies adoption implies the appliance of technologies in quick tooling as well as in final products production (SmarTech Markets Publishing, 2014). In this phase, additive manufacturing technologies adoption can help in final parts production through molding and tooling, while the most advanced adopters use these technologies for the final parts production. Also, all the improvement categories as a result of additive manufacturing technologies adoption are considered, including supply chain optimization, cost reduction and time to redesign existing and to produce new components.

Additive manufacturing technologies have become a standard practice in contemporary production and product development. In a BMW assembly plant in Regensburg, Fused Deposition Modeling (FDM) technology is still important component in vehicle prototype design. However, in the last few years BMW has expended the usage of FDM technology to other fields and functions including direct digital production (Schmid, 2013). Whereas the use of additive manufacturing technologies enables the production of complex geometrical shapes, they can also significantly increase the efficiency of tool designers and improve manipulative characteristics. FDM production process is very suitable for a complex part production and is growing in importance as an alternative method for complex components production in small quantities.

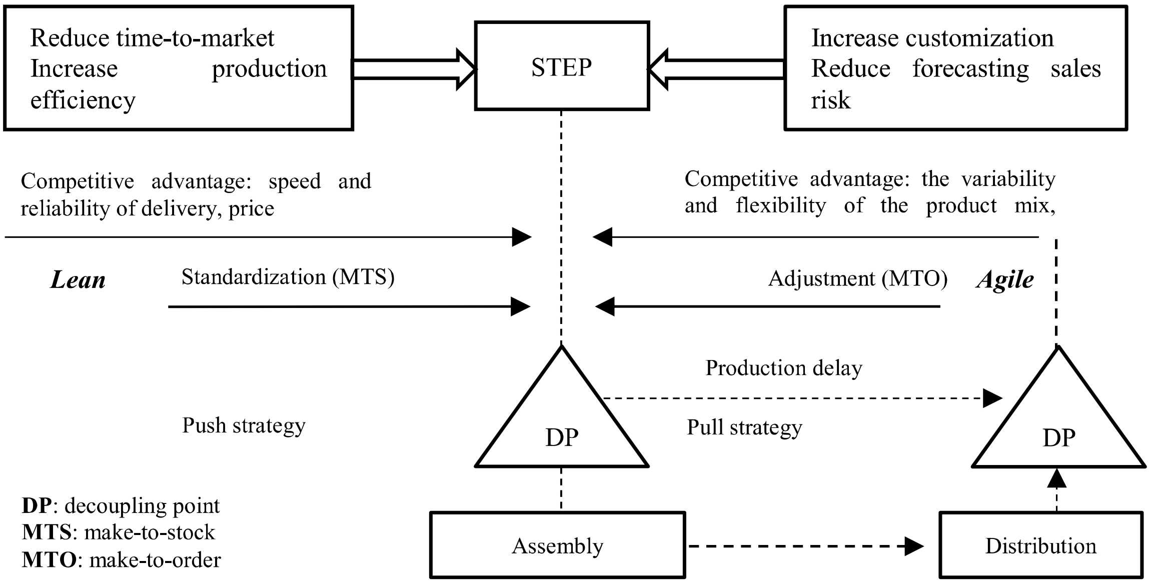
3.1. The influence of additive manufacturing technologies adoption on lean and agile concept of supply chain management in the automotive industry

An ongoing academic discussion on how to achieve the speed of response to the customer requirements in the supply chain is all about the Lean, agile and Leagile concepts (Christopher, 2000; Christopher & Towill, 2001; Mason-Jones et al., 2000).

The goal of the Lean philosophy is to achieve zero value of waste, and as for the supply chain integration, Lean paradigm goes much further than any other approach in order to set up connections between companies and thereby to integrate suppliers and customers through Kanban or other allocation systems. The center of Lean philosophy is the focus on reducing the time to market. MacDuffie et al. (1996) pointed out that, for the automotive industry, Lean plants are capable of producing more complex products in short series, which potentially gives them the advantage of faster response to changes in the customers' demands. As a reaction to the rigidity of the timetable in the Lean production, agile production approach appeared which promotes two main concepts to achieve flexibility (Kidd, 1994): postponement of decisions on production and product late configuration, in order to respond to customer demands by assembling products to order.

Characteristics of Lean and agile supply chain meet in the decoupling point, which plays the key role in the supply chain and separates Lean and agile parts of the supply chain model (Christopher, 2005, p. 120). Figure 3 illustrates the adoption of Lean and agile strategies in the automotive supply chain, where the implementation was mainly focused on the production until now. In that way, the productivity and goals quality inside the plant are set out at the expense of the value perceived by the customer (Holweg, 2002a: 65).

Figure 3. Lean and agile strategy in the automotive supply chain



Source: adapted from Ambe, I.M. & Badamhorst–Weiss, J.A. (2010). Strategic Supply chain framework for the automotive industry. *African Journal of Business Management*, 4(10), p. 2118.

This method of implementing the Lean production strategy resulted in localized optimization where unnecessary seconds are eliminated from the production, while the factory overproduces a two-month vehicle supply for the market. So, in order to avoid negative consequences of using only one of the production strategies, Fisher (1997) suggests the use of all three approaches in combination.

The Manufacturing 21st century report defines nine key challenges for the automotive industry in order to transfer from the make-to-stock and sell-from-stock model to build-to-order model (Holweg, 2002, p. 183-184): (1) dependence of industry on economies of scale, (2) creating a system of producing vehicles in low volumes at reasonable cost, (3) quick delivery of vehicles with custom features – within three days after the order, (4) additional reduce in production volume, (5) enabling the configuration of same components in different ways, (6) stimulate workers, (7) processing the customer participating in order fulfilment, (8) to create an ordering system that will instantly check the combination of customer demands for the security and feasibility of production, (9) managing and controlling big data.

Efficiency in the automotive supply chain can be improved by using the JIT principles, flexible production systems and Lean strategies in supply chain management (Howard et al., 2006), while the effectiveness can be improved through the strategies of quick response and agile supply chain (Perry et al., 1999; Christopher, 2005). In order to secure market share and survival, the supply chains need to satisfy future customer demands. Anticipation of demand is one of the processes which necessarily brings the element of insecurity in the supply chains. However, the accuracy of forecasting can be improved by reengineering the supply chain, especially by reducing the time-to-market (Towill, 1996, p.17), to which additive manufacturing technologies may significantly contribute.

Suri (1999, p. 165) suggests quick response manufacturing (QRM) as an alternative to Lean production, claiming that Lean strategy is not directed to reducing the time-to-market. However, considering that ability of suppliers to quickly respond to market demand is the precondition for the success of the quick response strategy, Fisher et al. (1994, p. 84) question the applicability of the quick response strategy or the JIT concept if the production facility depends on the suppliers who slowly react to market demands. This segment of the Lean strategy offers the possibility to use the opportunity of fast prototyping and final production with additive manufacturing technologies.

Gobetto (2014, p. 49) highlights five contemporary criteria for reducing the time-to-market and assuring the level of quality needed from the first delivery to the customers: (1) conducting various activities at once - simultaneous engineering by involving suppliers into the product design; (2) for the designing CAD programs are used, applying precise predicative analysis; (3) developing specialized tools by using modern CAD techniques together with the process of transformation of materials and simulating prefabricated components; (4) fast prototyping - for that purpose modern tooling techniques are being used (e.g. additive manufacturing technologies) and (5) the pre-manufacturing phase by using finished tools.

Until now, the use of additive manufacturing technologies in the automotive industry mainly contributed to the development and making of prototypes, without using tools and molds which creates the highest financial cost in developing new products. Although it is assumed these technologies will not be widespread in mass production, Rhienhart (in: Sedwck, 2016) points out that by the possibility of producing a product composed of several components, additive manufacturing technologies will significantly reduce production costs and weight of components, which represents the key precondition for sustainable production.

From the perspective of automotive supply chain, advantages of the additive manufacturing technologies adoption in the production processes involve the possibility of introducing Just-in-Time production system in order to reduce stock of semi-products and final products (Dekker et al., 2003, p. 186). Because of its manufacturing possibilities, additive manufacturing technologies are perceived as sustainable production system which can be settled in various links of the supply chain. The additive manufacturing technologies adoption can potentially reduce the phases of traditional supply chain; the production can be moved closer to the final customer, whereas net effect would be shortening of supply chains considering the reduction of the final products storage needed. The product customization is one of the reasons why additive manufacturing technologies will lead to great changes in managing supply chains. A large number of intermediaries, on which today's production depends, will potentially no longer be necessary because of the additive manufacturing technologies adoption.

Additive manufacturing technologies adoption will bring the great savings to producers in terms of the labor costs and potentially in reducing the warehousing, handling and distribution costs of product components. The consequences of additive manufacturing technologies adoption in automotive industry can be massive:

- manufacture-to-order strategy could drastically reduce the level of final product stock;

- build-to-order production strategy could substantially affect the manufacturer-retailer relationship - retailers may become “shopwindows” for manufacturers without their own stock.

Many authors envisage the production of spare parts on demand in the near future, practice which significantly affects the need for having final parts stock, accelerates fulfilling the demands of end customers and dramatically affects the supply chains (Holmstrom & Partanen, 2014; Khajavi et al., 2014; Walter et al., 2004). Although additive manufacturing technologies adoption can increase the costs per product unit, by reducing warehousing costs and outdated products, overall supply chain costs could be lower than those in traditional production supply chains. From the supply chain perspective, additive manufacturing technologies also represent the tool suitable for strengthening the flexibility of production systems (Grimm & Wohlers, 2003; Hopkinson & Dickens, 2001).

For agile concept of the supply chain management, the advantages of additive manufacturing technologies adoption are multiple. In agile supply chain it is important that the manufacturers are able to respond to production demand changes fast, whether it is a change in a volume of production or a change in product characteristics (Aliakbari, 2012, p. 47). The use of additive manufacturing technologies reduces the production time because of the possibility of starting the production process right after finishing product design in CAD program. Using traditional methods of producing a new product usually takes several weeks to manufacture the tools needed before final products production can start (Atzeni & Salmi, 2012, p. 1154).

When talking about the additive manufacturing technologies adoption in the production processes, there is no difference between the simple and the complex objects. Unlike the traditional production methods, production of complicated product structures is not more expensive than the production of products with simpler geometrical features. From the perspective of the supply chain management strategy, the product customization gets into the whole new dimension under the low-cost agile strategies category (Nyman & Sarlin, 2013, p. 6). In this case, it is a complete customization, not the massive customization meaning that the product can be completely adjusted to the demands of the final customer without any limitations, whereas the modular structure of product is no longer necessary. Although it has a less direct impact on the supply chain strategies, it can open new possibilities in the product customization to the final customers. Considering the concept of customization by Alfred et al. (2000, p. 100), where the customer is completely involved in the production and the design of vehicles, quick production technologies will have a great impact in the creation of agile supply chains.

Besides affecting the supply chain agility, the ability of producing several various specialized products with one machine also affects the Lean concept of supply chain management through saving and eliminating the need for physical distribution of final products. This concept of production can drastically reduce logistics and production costs. Berman (2012, p. 157) points out that compared to traditional methods, 3D printing technology can reduce the amount of waste by 40 percent in the metal machining. Therefore, from the supply chain strategy perspective, the use of additive manufacturing technologies can potentially have a great impact on total price of the production and enable complete use of the Lean concept of supply chain management.

Lean paradigm is mostly about the reduction in material waste, the cost and the time for production. Furthermore, in the traditional production methods one of the largest costs for the manufacturers is the tools price. Therefore, in the context of the additive manufacturing technologies adoption in the production process, eliminating the need for tools drastically reduces the overall cost of production. According to Tuck et al. (2007, p. 12), the technologies of quick production will contribute to the Lean methodology in a way that companies will produce spare parts only when needed through JIT technologies and removing unnecessary waste in the supply chain. Considering that technologies for quick production require only 3D CAD data and raw materials to start the production, their use will result in material distribution and warehousing costs reduction for work in progress.

Although automotive industry offers variations in final products (the colour of the body, cover, etc.) this is not the core change category. But, considering the advantages of additive manufacturing technologies adoption, such as the ability of producing complex structures from digital data designed in cooperation with the final customer, core customization of vehicles becomes possible.

Following the above said, it is obvious that the quick production technologies, together with additive manufacturing technologies, are able to produce on final customer demand. With this concept, situations of insufficient or outdated inventories could be avoided, considering that the company is obligated to keep only raw materials on stock (Tuck et al., 2007, p. 15). With the reactive production approach, the use of additive manufacturing technologies reduces time-to- market, which is crucial for both Lean and agile concepts of supply chain management (Nyman & Sarlin, 2013, p. 7).

4. CONCLUSION

Based on the available literature in the field of additive manufacturing technologies, automotive industry, supply chain management and related factors in the field of logistics management, this paper analyzed the influence of additive manufacturing technologies adoption on lean and agile concepts of supply chain management in the automotive industry.

Considering the objectives defined in the introductory part of the paper, the following can be stated: the first paper objective was achieved by in-depth analysis of existing scientific research and actual contributions in the field of additive manufacturing technologies and different dimensions of the supply chain management, with special emphasis on the automotive supply chain; the second paper objective was achieved by the critical analysis of theoretical approaches in analyzing the impact of additive manufacturing technologies adoption in the automotive supply chain management. Therefore, the conclusion is that the objectives of this paper have been fully achieved.

In addition to the systematic and comprehensive review of the domestic and foreign literature and critical analysis of previous research in the field of additive manufacturing technologies adoption in the supply chain, the contribution of this paper is in fact that this is the first comprehensive study of additive manufacturing technologies adoption in the automotive industry and automotive supply chain management, as one of the fastest growing industries in additive manufacturing technologies adoption. Additive manufacturing technologies have potential to significantly affect modern businesses, especially in terms of the potential implications to supply chain management. Therefore, future research should consider the effect of additive manufacturing technologies adoption on the supply chain management dimensions such as supply chain integration, supply chain flexibility or supply chain performance. In this context, quantitative research is suggested.

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