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REVIEW ARTICLE / DERLEME MAKALESİ

The Disruptive Nature of 3D Printing Technology on Mass Customization and Supply Chain In The Context of Environment and Economy

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Abstract
Today's production paradigm is shaped by mass production, where production processes and tools are standardized, expertise is not taken much into account, and the same products are produced either in batches or massively in small varieties. Production is carried out in factories in certain centers, and the products produced are often distributed all over the world. There is a need for a multi-agent supply chain network and supply chain management with the stages of delivering the products to the final consumer, starting from the pre-production stage. It has become clear that the need for a complex supply chain network by producing products from a single center is no longer economical and environmentally friendly. In recent years, consumers have started to think about the harmful effects of the products they buy. Changing customer needs and demands have also made companies consider the mass customization production model. Recently, three-dimensional printing technologies, also defined as additive manufacturing technology, have emerged as a new production technology. With this disruptive technology, production models and supply chain networks are subject to change and transformation. In this study, the environmental and economic benefits of 3D printing technology are analyzed in the context of mass customization production model and supply chains. The following comments were made as a result of the study. 3D printing technology enables production at distributed points instead of a central production point. In this way, production costs are reduced as many intermediate production points are eliminated. In addition, logistics costs and logistics-related carbon emissions are also reduced. With decreasing costs, development is provided in local economies.
Key Words: 3D printing, Mass customization, Supply chain management, Environment, Ecology

Öz
Günümüz üretim paradigması, üretim süreçlerinin ve araçlarının standart hale getirildiği, uzmanlığın pek dikkate alınmadığı, aynı ürünlerin partiler halinde ya da kitlesel olarak az çeşitler halinde üretildiği seri üretim ile şekillenmektedir. Belirli merkezlerdeki fabrikalarda üretim yapılmakta ve üretilen ürünler çoğu zaman tüm dünyaya dağıtılmaktadır. Ürünlerin üretim öncesi aşamadan başlayarak nihai tüketiciye ulaştırılması aşamaları ile çok etmenli bir tedarik zinciri ağına ve tedarik zinciri yönetimine ihtiyaç vardır. Tek bir merkezden ürün üreterek karmaşık bir tedarik zinciri ağına duyulan ihtiyacın artık ekonomik ve çevre dostu olmadığı ortaya çıkmıştır. Son yıllarda tüketiciler satın aldıkları ürünlerin zararlı etkilerini düşünmeye başladılar. Değişen müşteri ihtiyaç ve talepleri de firmaları kitlesel bireyselleştirme üretim modelini düşünmeye sevk etmiştir. Son zamanlarda, eklemeli imalat teknolojisi olarak da adlandırılan üç boyutlu baskı teknolojileri, yeni bir üretim teknolojisi olarak ortaya çıkmıştır. Bu yıkıcı teknoloji ile üretim modelleri ve tedarik zinciri ağları değişime ve dönüşüme tabidir. Bu çalışmada, 3D baskı teknolojisinin çevresel ve ekonomik faydaları, kitlesel bireyselleştirme üretim modeli ve tedarik zincirleri bağlamında analiz edilmektedir. Çalışma sonucunda aşağıdaki yorumlar yapılmıştır. 3D baskı teknolojisi, merkezi bir üretim noktası yerine dağıtık noktalarda üretim yapılmasını sağlar. Bu sayede birçok ara üretim noktası ortadan kalktığı için üretim maliyetleri düşürülür. Ayrıca lojistik maliyetleri ve lojistik kaynaklı karbon emisyonları da azaltılmaktadır. Düşen maliyetler ile yerel ekonomilerde gelişme sağlanmaktadır.
Anahtar Kelimeler: 3D Baskı, Kitlesel bireyselleştirme, Tedarik zinciri yönetimi, Çevre, Ekoloji

1. INTRODUCTION

Recently, consumers have started to approach more consciously about climate change and environmental problems. They frequently question whether the products they buy harm nature or their health as a result of mass production processes. This situation led the producers to think about nature and environmental problems and to review their production processes from an ecological point of view. While companies are working on cost, delivery times and quality, they take green performance into account to reduce or eliminate the pollution and negative environmental effects. Purchasing environmentally friendly raw materials used in production, improving fuel efficiency, and reducing emissions from transportation vehicles are important problems encountered in supply chain management. At this stage, it is clear that business models have started to change. The advantage of using 3D printing technologies in the production processes of the enterprises will reduce material-related waste, logistics-related emissions, shortening of production time, energy consumed for production, energy-related emissions, and will also reduce production costs.

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Mass production based on fossil fuels as common energy source is getting replaced by mass customization, where customer demand is the main drive. In addition, customers pay special attention to the design of the products they will buy with eco-design thinking.

Once the production rate exceeds a certain threshold value for producing goods and services through especially mass production systems, then majority of people become pure consumers according to analysis made by Ivan Illich (1977). Since mass production requires very costly systems, the population over the threshold value becomes passive in economies. On the other hand, mass production needs large amount of sales to meet Return of Investment (ROI) over time, it is also criticized for causing planned obsolescence (Çetiner and Gündoğan, 2014). The main output of planned obsolescence is oversupply. As a result of this mass consumerism and oversupply produced in the current mass production paradigm, rapid resource consumption, carbon emissions occur due to the production being mostly based on fossil fuels as energy source. While these are the environmental problems of mass production, the production of low quality and low value-added products are also economic problems. A paradigm shift is required for ecological and economic sustainability for supply chain management systems. Existing problems and solutions should be addressed with a holistic paradigm (Çetiner and Gündoğan, 2014). Disruptive technologies, such as 3D printers and other mass customization methods might help change paradigm from a harmful production era into more environment friendly one. Supply chain systems are bound to change due to this paradigm shift.

As a result of the sensitivities that have developed about ecology and the protection of the natural environment in recent years, companies have started to transform themselves. In this transformation phase, they realized that supply chain partners are also important and effective for the management of the natural environment.

The main question that drives this article is to what extent additive manufacturing technology, 3D printing, is transforming mass production to mass customization and supply chain applications, and is linked to environmental management. In order to understand the transformative and destructive power of 3D printers, binary analyzes were made on the topics of mass customization and supply chain. These can be listed as the connection between mass customization and 3D printing technology and the connection between supply chain and 3D printing technology. The benefits of 3D printers to end users, manufacturers, supply chain management, environment and economy have been compiled and interpreted in the context of 3D printers, mass customization and supply chain. As a result of the study, the benefits of 3D printing technologies to local economies, the improvements to be made in supply chain management and the ecological benefits provided by both the use of recycled raw materials and the reduction of logistics-based carbon footprint are discussed.

2. LITERATURE REVIEW

The current manufacturing occurring worldwide today is carried out through mass production paradigm. The primary aim of manufacturing technology is to produce the designed products at the lowest cost and with the most accepted quality quickly. Factory type production existing mainly as mass production requires very high production volumes with very low varieties under certain standards where operator skill levels do not need to be as high as in other production models (Ryan et al., 2017).

From a classical point of view, production can be defined as one-to-one-based personalized production or mass production. Although mass-produced products are much cheaper than tailor-made production that requires manual dexterity and low skilled labor, it gives little importance to customer requests and expectations. With the advent of additive manufacturing, the definition of classical manufacturing started to change. Additive manufacturing provides engineers with the opportunity to produce computer-aided, personalized and uniquely designed products by using a combination of automated processes and standardized materials (Melchels et al., 2014). Additive manufacturing or 3D printing involves the production of a prototype or final product in a very short time by accumulating layers. This new technology leads to a radical change in the production system based on mass production. With 3D printing, production processes are undergoing radical changes. With reduced production steps and work processes, raw material and energy losses are minimized. Time spent on production and logistics activities is saved (Panwisawas et al., 2020).

Energy efficiency is one of the goals sought to be improved in supply chain management. Manufacturers are using digital technology applications or replacing existing technologies with clean technology to improve their energy efficiency. 3D printing, which is one of the innovative applications, causes a change in existing production models due to its advantage in reducing energy use. Resource efficiency with 3D printing is achieved by 3D printing technology reducing the need for materials and wastes used in production, and the same material can be used repeatedly (Feng et al., 2022).

Household products, toys, small parts, ornaments, figurines are the first products produced with 3D printers (Majumdar et al., 2018). With many studies, it is seen that houses and boats are also produced with 3D printers. In addition to these, aerospace industry application can also be offered. Nickel-based superalloy, developed for turbojet engines and suitable for high temperature operations, is widely used in the aerospace and energy industries. Approximately 10% of the super alloy used in the gas turbine production of turbojet engines is used, while the remaining material is waste. 3D printing can replace traditional manufacturing and be used to produce complex geometries such as turbine engines without causing waste (Panwisawas et al., 2020).

Nowadays, plastic packages, plastic boxes and disposable products made of plastic are used quite frequently. Tons of plastic waste is produced every day. Plastic remains intact in nature for many years and harms nature. However, microplastics also pose a danger to the soil and aquatic ecosystem. In terms of waste management, it is aimed to prevent waste generation instead of collecting and disposing of wastes. In order not to create plastic waste, the production and consumption of plastic should be reduced, but in today's conditions, it is not enough to prevent the use of plastic. In cases where waste generation cannot be prevented, waste reduction and waste reuse gain importance (TMMOB, 2021). 3D printers offer innovative solutions for the reuse of plastics. At this stage, plastic wastes can be converted into plastic filaments and reused.

3D printing technology, which gives users the right to personalize through the opportunity to produce their own original designs, also offers various material alternatives. It is a desired feature that these materials, also known as additives or filaments, do not harm ecology during the production phase. At this stage, studies are carried out on wood and sawdust materials due to their renewable properties (Cengiz and Aktepe, 2022).

In this study, the discussion of the destructive and transformative power of 3D printer technology was made through mass customization and supply chain networks. These two main points are analyzed in the context of how mass production, which is the main element of the current economic model and has a centralized structure, can be transformed into decentralized local economies. Compiling and analyzing a limited number of studies on strengthening local economies, ecology, creating a circular economy at minimum waste level, and making policy and method recommendations distinguish this study from other studies in the literature.

2.1. Additive Manufacturing and 3D Printing Technology

(Berman, 2020) explained three main characteristics of disruptive technologies: Innovation, creating new markets and a more efficient production technology with less costly materials. With a new production model for consumers, it makes consumers as producers, improves delivery speed, eliminates intermediate producers and hence leads to transformations in the existing supply chain by enabling customers to customize the design of the product they want to have and enabling local and small-scale manufacturers to survive with new business models against large companies. It epitomizes the destructive nature of 3D printing technology. Additive manufacturing is one of the best developing technologies for the standard of living, localization and the ability of local businesses to compete with global companies (Shree et al., 2019).

3D printing technology proverbially Rapid Prototype Manufacturing (RPM), and in terms of production technology, 3D printing technology is also known as Additive Manufacturing (AM). 3D printing enables the production of objects by stacking certain materials layer by layer based on a 3D model file that is designed and maintained in digital form. It is a technology that uses different printing techniques and printing tools as well as different materials. 3D printing websites provide consumers to print personalized 3D models of the products they want by changing design parameters (Sun et al. 2022). 3D printing is a hard technology which is used to manufacture three-dimensional objects based on the digitally controlled deposition of successive layers of material until a final object is produced (Feng et al., 2022).

3D printing or additive manufacturing has developed in recent years and has become low-cost and easily accessible and usable as a desktop compared to when it first appeared. The potential to create new forms, enable mass customization, and support low-volume, distributed production has made 3D printing or additive manufacturing seen as a disruptive technology that will revolutionize design and fabrication (Corsini et al, 2022).

The advantage of 3D printing in terms of energy efficiency is that less energy is needed in the printing process and also resource efficiency is the reduction of waste as a result of production, the need for more pleasant raw materials, high deficit prediction ability (Feng et al., 2022). Apart from the electrical energy produced from fossil fuels for printing, electrical energy produced from renewable energy sources may also be sufficient. The consumer is also the producer of the product and can easily print with the electrical energy produced from renewable sources at home. Contrary to machining, with 3D printing technology or additive manufacturing, a clean production is ensured because very little waste is generated. In addition to these, making designs via computer minimizes the margin of error arising from the design (Toğay and Sağıroğlu, 2019).

In traditional production, spare parts are stored in anticipation of need. On the other hand, spare parts are produced as needed in additive manufacturing. The use of 3D printing reduces or eliminates uncertainty in demand. 3D printing allows companies to print parts for devices that are no longer manufactured. Thus, devices and machines that cannot be used due to lack of spare parts are continued to be used instead of scrapped. According to a research, a family using one 3D printer to print only 20 domestic products per year (about 0.02% of the products available) can expect to save between $300 and $2000. This means that a simple 3D printer is an economically attracting enterprise for the average US household already (Wittbrodt et al., 2013). Currently, the costs of 3D printers for printing fully functional products from materials such as steel, ceramic, glass etc are not cost efficient for ordinary families. The technology is expected to lower the costs to be affordable by them.

2.2 Supply Chain

Supply chain is an integrated process in which raw materials are converted into final products and distributed to customers, as well as being very relevant to supplier management, which deals with materials and production management, facility planning, customer service, transportation and physical distribution, and information flow. Manufacturers, distributors, wholesalers and retailers are also actively involved in this process. Analyzes and designs are made for recycling, remanufacturing and reuse, which includes reverse logistics and aims at product recovery in a multi-factor, multi-stop supply chain that starts with the source of supply and ends at the point of consumption (Shree et al., 2019).

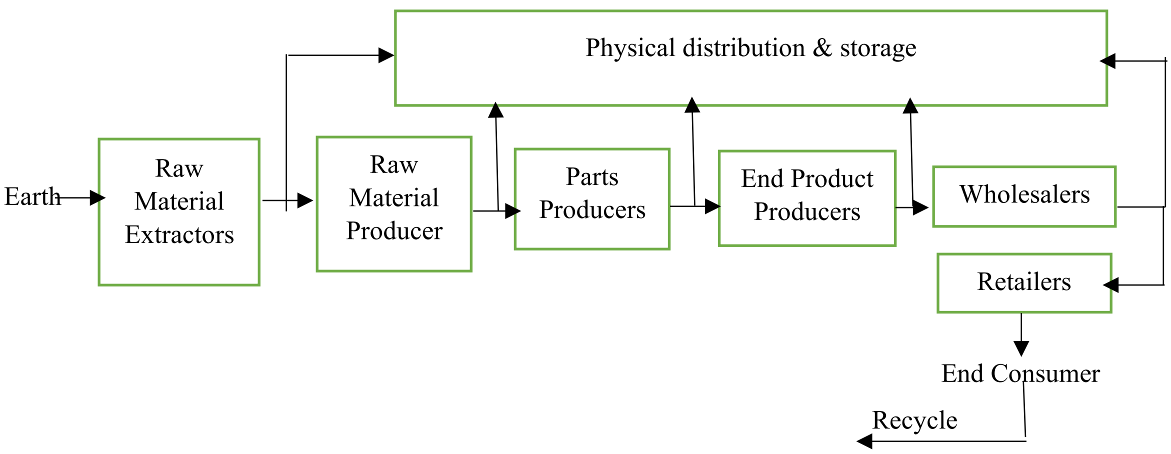

Figure 1. Events and participants in the supply chain (Source: Adapted from Yılmaz, 2003)

Figure 1 shows the events and participants in the supply chain. The process starts with the acquisition of raw materials and minerals and progresses to manufacturers, wholesalers, retailers and end users. Supply chain management also includes recycling or reuse of products or materials. Supply chain management involves procedures such as planning, product design and development, resource planning, fabrication, installation, transportation, storage, delivery and finally distributed customer support. In an integrated supply chain, instead of manufacturers pushing the product towards end users, end customers pull stock.

The role of supply chain management and processes in environmental pollution is undeniable (Fang and Zhang, 2018). The use of fossil fuels from logistics activities causes greenhouse gas emissions. Warehouses are needed for raw material stocks. Electrical energy is needed for lighting, heating and cooling of these warehouses. The supply of electricity from fossil fuels is one of the factors that pollute the environment and deepen the climate crisis.

2.3. Mass Customization

Today, the customer has realized the importance of his own wishes and has started to oppose the impositions. Customers no longer object to the color, they also specify the features they do not want and inform the manufacturer of their own needs and take part in the design of the product. Many industries such as automobile, computer, construction, machinery industry have begun to transform their production and management styles from mass production to mass customized production in order to provide changes and innovations in technology, product diversity and flexibility.

Table.1: Comparison of mass production and mass customization

Properties	**Mass Production**	**Mass Customization**
Focal Point	Efficient fabrication	Diversity and customization
Purpose	Easiness and control	Resilince and quick response
Object	Market share	Customer share
Aim	As a result of the design, manufacturing and delivery stages of the products, customers should be able to reach affordable products.	As a result of the design, manufacturing and delivery stages of the products, customers should have access to individualized and affordable products.
Decision Maker	Producer	Customer and producer
Basis of Manufacturing	Forecasting demand	Demands created by customer orders
Property of Demand	Unfluctuating demand	Fluctuating demand
Properties of Market	Large, homogenous market	Heterogeneous niche market
Product Development Process	Long	Short
Product Life Cycle	Long	Short
Amount of Production	High amount of production per orders	Low amount of production per orders
Choices of Product	Consumers can choose from limited options	Consumers can choose between a lot of options
Variety & Production	Limited level of production	Flexible production for product variety
Stock Management	Stock must be kept in every level of supply chain	There is no need to keep stock of finished products as sales occur before production.
Limitation of Production	Production to the stock	Production to the order
Quotation	Based on returned items, stocking cost and price reductions	The purposes based on mass production are not taekn into account
Production	Continuous manufacturing	Grouped and clustered manufacturing
Advance	A large community is targeted	A small community is targeted
Agility	Slow	Fast
Investigated Properties	Mass production	Mass customization
Reducing the Cost	Economies of scale	Economies of scope
Cash Flow	Inflexible due to intermediate stocks held in the supply chain process	Part or all of the payment has been taken because the product is sold before the production process
Logistic	Group orders that are similar	Group customized products based on customer order

Source: Adapted from Efendioğlu et al., 2016.

In Table 1, the comparison of mass production and mass customization can be seen as main features of production and supply chain management. The primary goal of mass production is to produce standard products at prices that anyone can buy. The main purpose of mass customization is to produce a sufficient variety of products and services so that customers can purchase exactly the products and services they want at affordable prices. Low costs in mass production are primarily achieved through economies of scale. Cost advantage in economies of scale is achieved by creating capacities large enough to produce a single product or service and minimizing the fixed costs per unit by producing large masses with the effective use of these capacities. Low costs in mass individualized production are provided by economy of scope. In scope economy, the aim is to produce a wide variety of products and services cheaper and faster with a single process.

3. 3D PRINTING TECHNOLOGY FOR MASS CUSTOMIZATION

3D printing leads to a paradigm shift in production by providing remarkable improvements in many performance criteria related to mass production. These criteria can be listed as fuel saving, energy saving, product development time, reduction in costs, increased durability, easier production of complex designs much cheaper and production of impossible objects with other manufacturing techniques and machines (Jordan, 2019). The fact that it can easily produce designs with complex geometry by making mass customization and distributed production possible, has led 3D printing being accepted as a revolutionary technology (Corsini et al., 2020). Mass customization is a new manufacturing paradigm that stabilizes the efficiency and customization capability of mass production. Alongside of traditional production, 3D printing decreases the need for tools and thus enables unfluctuating production that can transform 3D data directly into physical parts using digital production processes, considerably reducing customization costs and saving lead time. Complex geometry structures can be designed and produced with the desired materials by 3D printing or additive manufacturing (Sun et al. 2022).

There are also significant differences in the manufacturing processes enabled by the wide variety of 3D printing technologies available on the market. 3D printing machines range from desktop printers that can produce low-quality plastic components and cost a few hundred dollars, to industrial machines that can produce high-quality products from a variety of materials such as metal, plastic, ceramics, and cost hundreds of thousands of dollars (Ryan et al., 2017).

3D printing, which is a production technology suitable for mass customization versus mass production, has the characteristics of producing small quantities economically by pulling production from a global scale to a local scale, producing according to the individualized demands of customers and producing less waste. Low-cost, highly customized products, faster prototype development times, lower inventory holding costs, and highly flexible manufacturing facilities are the advantages of 3D printing versus the economies of scale that mass production provides (Berman, 2020).

3D printing provides various advantages to users. These advantages can be listed as time efficiency, keeping less inventory, reduction in production costs according to the zero waste policy and waste reduction, product personalization, feasibility of small production batches, reduced delivery times, flexibility in design, more effective use of creativity in the production phase, use of more color options (Ukobitz & Faullant, 2021). What is more, 3D printing provides many advantages over the current production model. Local production reduces the need for warehouses and lowers inventory costs. The speed of delivery to the customer increases. The need for large transport stocks is eliminated. Thanks to low stock holding costs, high production volumes are not required, where mass production provides price advantage in order to balance high stock costs. Complex parts such as gears can be produced without molding and cutting operations. No assembly is required as the number of component parts is also reduced. The production process, which takes weeks with the current production model, is replaced by days and hours. In the model of production from a single center and distribution to the local, the use of fuel from logistics causes a carbon footprint. With local production, a reduction in carbon footprint is achieved. Because 3D printing provides manufacturing flexibility, there is no need to stockpile large stocks or make significant discounts due to uncertainty in forecasting demand. In subtractive production, production is made by subtraction from the main material, while in additive manufacturing, production is made without loss of material. This results in less scrap and less assembly work is required. This provides a positive reduction in the carbon footprint of companies.

4. 3D PRINTING TECHNOLOGY FOR SUPPLY CHAIN

3D printing technology reduces the complexity of the supply chain. With this technology, production can be made as soon as the need arises. Thus, besides reducing the sub-steps that make up the production process, the amount of stock held also decreases (Mohr and Khan, 2015).

Table 2. Impact of 3D printing on supply chain network, governance, operation and output.

Sample	**1. Centralised manufacturing at a local production site**	**2. Fixed manufacturing plant at implementing company**	**3. Mobile manufacturing plant at implementing company**	**4. Distributed manufacturing at local production sites**
Network	Reducing the number of upstream tiers by eliminating the need for storage	Elimination of international and local suppliers, resulting in a reduction in the number of upstream layers	Elimination of international and local suppliers, resulting in a reduction in the number of upstream layers	Reducing international suppliers in the upstream layers and the creation of the upstream layers with local suppliers.
	Production takes place in a single center in the country and final outputs are carried to multiple distribution channels.	Direct distribution of final outputs to consumers with on-site production.	The mobile production facility goes to the production area. Direct distribution of final outputs to end users is ensured.	Distributed production is done with more than one producer in local production centers in the country.
	It is produced locally. Materials and tools are imported instead of the final product.	It is produced locally. Materials and tools are imported instead of the final product.	It is produced locally. Materials and tools are imported instead of the final product.	Finished products are sent to the end user.
	Design is distributed (international).	Design is distributed (international).	Design is localised	Manufacturing with 3D printers
Governance	There is cooperation between the design and production team	There is cooperation between the design and production team	Direct design and manufacturing.	Distributed supply chain.
	In the supply chain processes, information is shared through digital communication.	There is upstream information sharing between manufacturers in the supply and production of materials such as 3D printers and filaments.	There is improved information sharing downstream.	There is cooperation between the design and production team
		Information sharing between consumers and manufacturers	Reduced number of actors in supply chain.	Information sharing across supply chain simplified by digital communications.
Operation	Team work	Team work	User-centered	Participatory
	Increased circularity	User-centered	Enhanced circularity	Resilient
Output	On demand	Mass customisation	Customisation	Low cost
Example	Spare or repair parts	Prosthetics	Spare or repair parts	Prosthetics

Source: Adapted from Corsini et al., 2020.

In table 2, four supply chain archetypes transformed by 3D printing technology are examined through network, governance, operation and output criteria. In the network criterion, supply chain links have been created according to the location and geographical feature of the place where the production is made. In the governance criterion, supply chain analysis was made in the context of information sharing, relations and ownership in the design and production processes. In the process criterion, supply chain connections were examined through value-added and non-value-added activities. In the product criterion, supply chain relations have been emphasized through factors such as diversity, complexity and cost of products.

What is more, in the machining method based on extraction techniques, the final product is produced by cutting and drilling the main material. A significant loss of material and waste occur in this production process. Since the material used for production with 3D printing technology is added layer by layer, only the necessary material is used to produce the final product and there is almost no waste. Since the design of the product can be kept digitally in the computer environment, the design can be sent to the customer's location via the internet. Thus, time is saved, energy and fuel costs arising from transportation and carbon emissions caused by the fuel used in transportation are eliminated (Pirjan and Petroşanu, 2013). 3D printing has a significant place in supply chain management due to its advantages such as minimum production time, cost reduction, less waste of raw materials, quality improvements and product design according to customer requests. With 3D printing, a consumer can have the final product at home or workspace by downloading and printing the design. In addition, a supplier can easily have highly complex and customized products using 3D printing (Shree et al., 2019).

The effects of 3D printing technology on supply chains include reductions in lead times and transportation costs, less inventory holding, product quality and reliability, production flexibility, productivity, economies of scale, which is an important competitive advantage of mass production. What is more this technology makes them affordable for local and small businesses, supply chains sustainability, new business models and opportunities for new suppliers (Ryan et al., 2017). 3D printing enables digitalization and localization in supply chains, reducing energy use and resource demands throughout the production phase of a product (Shree et al., 2019).

5. THE CONNECTION BETWEEN MASS CUSTOMIZATION, 3D PRINTING TECHNOLOGY AND SUPPLY CHAIN

Material development has an important role in the spread of the use of 3D printing technology. 3D printing machines, which will be used in production, will need logistics once they are moved to their places, and the designs will be communicated to the users over the internet, and the users might start production at their location and have the finished product. In this process, there will be no logistics of finished products and thus the need for transportation fuel will decrease considerably. The most important item that will be needed for logistics here is the raw materials and materials to be used in production. Energy use and greenhouse gas emissions will decrease due to use of logistics style. There will be less logistics activities as the consumer can produce the products locally. However, since the production and distribution model in a single center will change, the amount of stock held will also decrease, and thus, a decrease in inventory costs will be observed. Since the products will flow directly from the producer to the customer and sometimes will be produced directly by customers, the retailers and intermediaries between the producer and the end consumer will disappear, and thus inventory and logistics activities will be reduced, and undesirable situations such as deterioration and breakage due to transportation will be eliminated (Silva and Rezende, 2013).

Localized and direct production formats are made possible with 3D printing. Therefore, it is predicted that it will have a notable effect on supply chains. These effects can be listed as shortening the supply chain, reducing complexity and increasing resource efficiency. In addition to these effects, 3D printing will enable rapid response to unforeseen events under significant resource constraints (Corsini et al, 2022).

One of the main advantages of 3D printing is that it supports product customization, which allows the consumer to actively participate in the design of the product according to their wishes and needs before production. Customer involvement can occur at different stages of the product manufacturing process and is defined as the point of order penetration (OPP) in supply chain management. OPPs, defined as the freezing point of product specifications, can influence the structure of customization in line with various supply chain managements. Six different OPPs and their associated supply chain structures are described (Figure 2). Through these six different points, the consumer can be included in the supply chain. Accordingly, customization covers circumstances from ship-to-stock (STS) where the finished product is reserved to the final distribution point, and engineering-to-order (ETO) where full customization takes place from the beginning of design and production (Ryan et al., 2017).

In mass production, manufacturers face transportation and stock-keeping costs, and by balancing these costs with the advantage of economies of scale and low labor costs that express high production volume, they provide price competition against local and small producers. With 3D printing, also known as additive manufacturing, processes such as molding, turning and cutting in subtractive manufacturing processes are not required and the costs caused by these processes are eliminated. There is no finished product production for stock, production is made according to the customer's order, thus reducing the risks and inventory holding costs associated with the finished and unsold product. Since design and production can be separated, transportation and storage costs are reduced and local production is also possible. Since products with complex geometries can be produced in one go, there is no assembly process and no labor cost arising from this process (Berman, 2020).

According to the literature review, production distribution of engineer-to-order penetration point is personal and manufacturing type is craft. Production distribution of buy-to-order penetration point is local and manufacturing type is job shop. Production distribution of make-to-order penetration point is regional and manufacturing type is factory. According to engineer-to-order penetration point, the design is made specifically for each customer, outputs can be produced at home easily and as craft manufacturing type small-scale products can be generated on desktop printers. According to make-to-order penetration point, available designs of spare parts are produced when required and printed near to the center of request. Low volumes are produced by using specialized equipment. The technology of 3DP provides craft operations at much lower costs and at much lower volumes of products since the 3DP is runned by the end user of the output (Ryan et al., 2017).

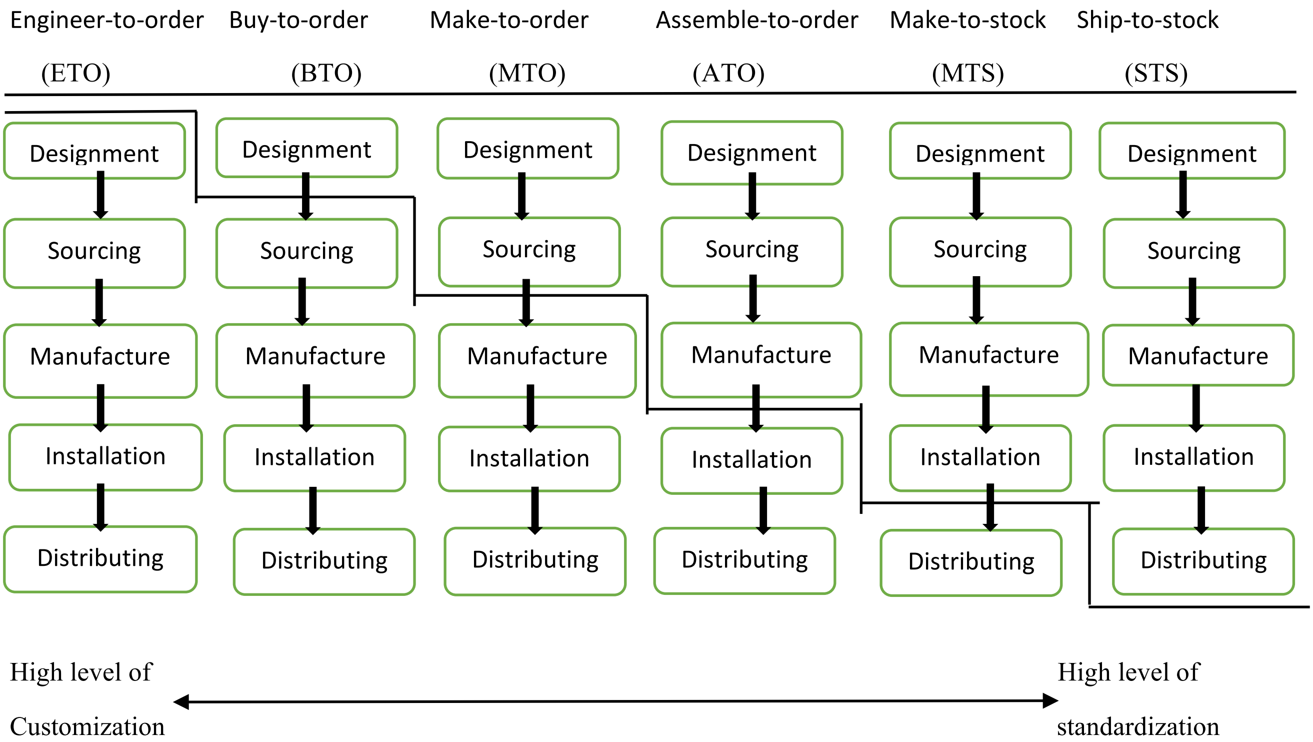

Figure 2. Six different OPP possibilities and their associated supply chain structured (Source: Adapted from Ryan et al. 2017)

Instead of overproducing for stock, 3D printing enables customized products to be produced according to customer requests and needs, thus reducing the unsold product inventory waiting in stock. In addition, the features of the design can be easily downloaded in the computer environment, access to the design features is both easy and fast. 3D printing also transforms the supply chain by changing the way products are designed, developed and distributed. Technological development in 3D printers for higher speed and the ability to use different materials are two important factors in the spread of 3D printing (Berman, 2020).

Thanks to individualized production, supply chains are shortened, planning accuracy is ensured, and thus inventory and scrap rates resulting from unsold final or intermediate products are reduced, out-of-stocks are eliminated because production is tailored to customer demands. In addition to all these, the return on investment in additive manufacturing equipment and materials is very fast because production becomes flexible with the same equipment and materials, and many different productions can be made with the same equipment. For preparing equipment and materials for production, additive manufacturing is more flexible than subtractive manufacturing methods such as machining, and thus production setup times are much less (Jordan, 2019).

With this technology, which leads to disruptive innovations, products can be customized in line with the expectations and demands of the customers. However, it has significant opportunities on the transformation of logistics and supply chains by reducing the inventory and transportation costs of industries.

Complex geometry structures can be designed and produced with the desired materials by 3D printing or additive manufacturing. With this technology, which leads to disruptive innovations, products can be customized in line with the expectations and wishes of the customers. However, it has significant opportunities on the transformation of logistics and supply chains by reducing the inventory and transportation costs of industries (Shree et al., 2019).

6. IMPLEMENTATION FOR POLICY AND PRACTICE

Using existing plastics as filaments instead of creating filaments for 3D printers from scratch will be an ecological practice within the scope of waste management. At this point, municipalities have important responsibilities in collecting plastic waste and recycling these wastes at the local level. Filament suppliers and municipalities should work together. Establishing distributed recycling centers instead of a single recycling center will also reduce logistics costs. Logistics costs should also be taken into account in transporting locally collected waste to recycling centers and transporting it to suppliers as an additive to be reused.

Although the demand for 3D printers is increasing day by day, many people are not aware of this technology. Comments that 3D printers are difficult to use also have negative effects on those who are curious about this technology. 3D printer manufacturers and vendors can develop joint projects with schools for the dissemination and awareness of this technology. The attention of children and young people can be attracted by producing the product they design and want.

Inability to reach raw materials with quality is one of the problems encountered in 3D printing technology. 3D printing technology is very suitable for local and distributed production in line with the production model. Access to local materials should also be possible in this direction. All actors can come together and interact, easily solve existing problems, and contribute to each other in product and process development, with the online market that brings together local producers, customers and material suppliers (Garmulewicz et al. 2018).

3D printing technology has a significant impact on creating local entrepreneurial ecosystems and supporting local economic development (Beltagui et al. 2020). It is a positive production technology for small and domestic producers that it can be used easily in any environment, is capable of meeting the needs of many sectors, and produces according to the special needs and designs of the person. At this stage, companies that produce and sell 3D printing technology should cooperate with local users and share information. In order to create new entrepreneurship and innovation models, local governments such as manufacturers, users, as well as municipalities should be a part of information sharing.

Bringing the factory to the living room of the consumer, 3D printing technology brings many legal and ethical problems for policy makers, technology manufacturers and consumers who use this technology individually. The first of these is how to establish and ensure quality standards. Whether the use of designs found in digital environments constitutes an intellectual property violation is another issue. There are also factors that can threaten human health. Establishing standards in sectors such as pharmaceuticals and food, and how to ensure and follow-up that individual consumers comply with ethical rules in production are among the most important problems (Kietzmann et al. 2015). Academics, technology manufacturers, lawyers, and perhaps officials from the ministries of trade and technology should work together on these ethical and legal issues.

7. CONCLUSION

Today's production and consumption patterns are the most important main causes of the climate crisis, one of the world's problems. This problem facing humanity leads to various environmental, political, social and economic problems (Gündoğan and Çetiner, 2014). With the paradigm shift of mass manufacturing around which production policies are shaped by continuous growth, continuous employment discourses, it has begun to leave its place to disruptive technologies. Disruptive technologies, including 3D printers, will be able to improve processes, performance and cost efficiency by eliminating intermediaries, simplifying existing supply chains and enabling on-demand production (Ukobitz and Faullant, 2021).

When more environmentally friendly, that is, greener, methods are applied in supply chain management, environmental problems arising from production processes may decrease significantly. The use of nature-friendly raw materials and materials in the design and production of products can eliminate the environmental problems that products will cause throughout their life cycle. Instead of the production model for stocking from a single center, it should be aimed to distribute the production locally. Thus, the stock levels of the companies will decrease, the product quality will increase, the delivery times will decrease as the finished product does not come out of a single center and the products are not delayed and damaged during visits to intermediaries (Fang and Zhang, 2018).

With 3D printing, which is a production technology suitable for mass customization, the economic model dominated by mass production is pulled from the global scale to the local scale, leaving it to mass individualization where production is made in smaller quantities, which can respond to customer demands and has the ability to produce less waste, instead of the economy of scale where mass production is advantageous.

The ability of 3D printing technology to produce locally and directly without the need for intermediaries is thought to change and transform supply chains. It is foreseen to shorten supply chains, reduce complexity from production and logistics, and increase resource efficiency (Corsini et al., 2020). The destructive and transformative power of 3D printing technology on the global economy and business models is important to be emphasized. The ability to produce the product at the customer's home outside the factory environment or to produce products at distributed production locations without being tied to a single production location can increase the competitiveness of local and small businesses, reduce economic imbalances, and reduce fuel use and carbon emissions from transportation (Pirjan and Petroşanu, 2013).

The following suggestions can be mentioned for the use of 3D printer technology by many people. Studies should be carried out on the optimization of materials such as wood and sawdust with renewable properties, which are used as filament raw materials in 3D printers. However, there is a need for studies on plant-based filaments.

The inability to achieve the desired quality in the products printed with 3D printers is a weak point of this technology that needs to be developed. Durability is also lacking in providing the desired condition in 3D produced parts. Studies should be carried out to improve quality and durability criteria. In response to these two weak points, the customization of production saves time and costs by eliminating unnecessary production processes. As elements such as quality and durability are improved with studies, 3D printers will become very attractive to users.

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