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Additive manufacturing in supply chain management

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ADDITIVE MANUFACTURING
IN SUPPLY CHAIN MANAGEMENT

Abstract

The business opportunities of additive manufacturing (AM) technology can be reflected in its supply chain management relevancy. This working paper focuses on the link between the challenges on engineering side and how to translate the potential benefits of the technology to supply chain dilemmas.

Keywords: additive manufacturing, production, supply chain management

AZ ADDITÍV TERMELÉS
AZ ELLÁTÁSI LÁNC MENEDZSMENTBEN

Absztrakt

Az additív termelési (AM) technológia üzleti lehetőségei leginkább az ellátási lánc menedzsment tükröződhetnek. Ez a műhelytanulmány arra a kapcsolatra összpontosít, amely a technológia mérnöki korlátait köti össze azzal, hogy miként lehet a technológia üzleti lehetőségeit ellátási lánc dilemmákra átfordítani.

Kulcsszavak: additív termelés, gyártás, ellátási lánc menedzsment

Contents

1) General concepts of AM in supply chain management

In order to put additive manufacturing in the supply chain context, it needs to be stressed that AM can have an impact on certain industries in a different way. What are these distinct industries, and what are their characteristic features which separate them from each other?

The product-process matrix depicts the link between the level of standardization of the product that needs to be manufactured, and the production processes. The vertical axis describes the technology employed to deliver the manufacturing objectives, and can be general, flexible on one end of the scale, and are specially built to capitalize on the economies of scales on the other end of the scale. The horizontal axis describes the characteristics of the products, which can be unique, or can have unique features on one end, and can be standard, or is standardized to an extent that the product can be considered as a commodity on the other extreme. Both axes can have multiple values in between the extremes.

Figure 1. illustrates the well-known and widely used matrix (Stobaugh and Telesio 1983; Buker 1984; Hayes and Wheelwright 1984), which was modified here in order to position additive manufacturing on this 2-dimensional map. However, because AM is combining features of unique non-standard finished products, which could be produced either in small scale and in large scale; and the technology is both product focused (the printer is a highly specialized machine) and technology focused with highly flexible adaptation (the printer is building up only one product, layer-by-layer – still can make many others). Therefore, nomen est omen, AM is a projection on these two dimensions along a third dimension (the third scale could be called ‘combinative features’).

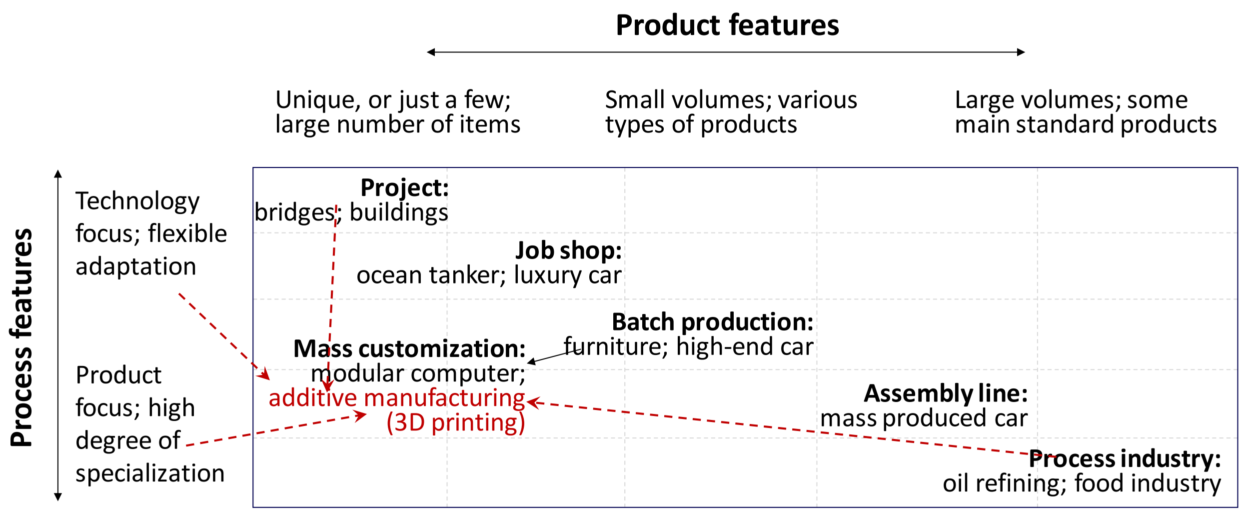

Figure 1. A custom-made product-process matrix

To be precise in the explanation of the product-process matrix, it needs to be mentioned that the industries are placed in the diagonal of the matrix. The reason for it can be grabbed by the two extremes on the other (not visible) diagonal: in the bottom left-hand corner, carrying out projects, or creating unique products on a highly specialized machine, which is built in a way that it can only produce that particular bridge, or that particular luxury car, would be a waste of resources, because building such a machine would be very costly, and the machine could not be used for any other unique products.

Similarly, in the upper right-hand corner producing standard products in large quantities using flexible technologies would be a waste of resources, because even if the machinery would be able to produce other products, we are not using these built-in features.

However, AM is combining these in conventional terms wasteful features as well, and could be used above any point of the matrix with variable efficiency. 3D printing has been used for creating buildings as well, however these are rather rare examples. However, the job shop is an ideal area for using AM efficiently, for products are created along unique designs for unique customer demand in low volumes.

Moving from prototyping and job shop to volume production, the efficiency along assembly lines is in the focus of the EIU study (2018), where it is argued that AM is effective for low-batch runs, making 50-100 pieces of something, however generally it is not cost-effective for making a large number of products. Rather customized products of short series are preferred, where "complexity needs to be mass produced". It is recommended that companies adopting AM find "niche" applications.

While analyzing the efficiency of 3D printing on the items of the diagonal in the product-process matrix, it is assumed that a trade-off can be calculated by comparing the average cost of conventional production and the average cost of AM-based production (even if it is rather a hybrid production). These cost comparisons need to take into consideration the unit time needed to produce one piece, and compare the costs at 10, 1000, and 100000 pieces. Even if the average cost of 3D printing might fall under the average cost of conventional production, the unit time factor might imply that AM does not suit mass production necessarily.

Until now, there are only a few business cases where AM is in live production, and not in testing or prototyping phase. The number of cases is important, because volume is needed to decrease costs – while the cost of 3D printing inputs proves to be the biggest hurdle for introducing the technology to mass production. On the other hand, AM is an effective tool for cutting the cost of variety.

2) Analyzing supply chain items

Having listed some of the most important general factors of 3D printing in production processes, it is worth turning to supply chain specific items. The following subsections are going to follow the order of the stages of a simplified supply chain, starting from the customers, as the key drivers of the whole supply chain process. The stages of the supply chain are linked by inventories, therefore the impact on inventories is discussed between the customers sub-sections and the manufacturing sub-sections.

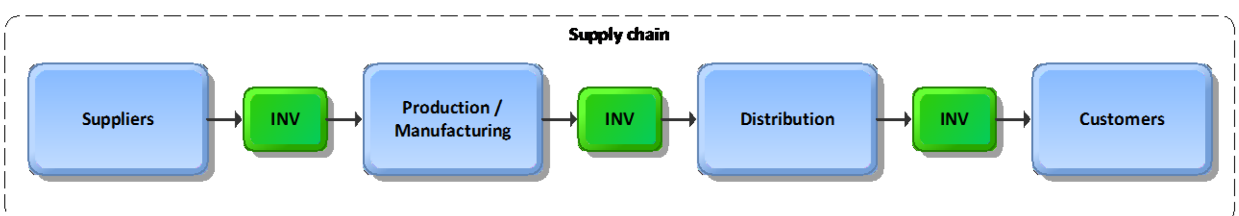

Figure 2. A simplified supply chain

2.1) Customization maximized

This sub-section deals with how the responsiveness to customer demand is affected by AM. Building on the product-process matrix described above, 3D printing is rather a high-flexibility mass customization tool, which enables producers to be more customer focused, driven by end-customer needs. The production cycle time might not fit mass production, however on the cost side there are clear benefits deriving from almost zero inventories throughout the whole process. However, the inputs of the process are expensive, and so if no breakthrough is achieved during the upcoming years, the cost benefits of no inventories might not offset the fact that orders of high quantities with short response time cannot be fulfilled (particularly, orders for mass-produced items). Thus, even if the 'customization' part is fulfilled at a high extent, even at a higher trajectory provided by new characteristics of the product deriving from the possibilities of the technology itself, the 'mass' part might be challenging of mass-customization.

There are particular industries, where parts not only can be customized, but need to be customized. The most common example is the health industry, or medical industry, where body part replacements, joints, prosthetic limbs need to be built according to the needs and properties of individual patients.

2.2) Order penetration point

As illustrated in the previous example, by adopting 3D printing, physical production could be moved further downstream in the supply chain, increasing flexibility, decreasing transportation costs and ecological footprint. Storing equipment, components in digital format, instead of a physical warehouse, the finished product can be placed closer to the customer in the supply chain. Based on the order penetration point (OPP) concept by Olhager (2003), this could mean make to order, or design to order in the information stream, while production needs to happen only in the last stages, right before shipment, or instead of long-distance shipments, the product does not necessarily need to flow through a distribution structure, if 3D printing happens geographically close to the customer. The following chart illustrates at which phase the OPP is in the supply chain, how deep can a customer demand penetrate into the supply chain, so that the product can be customized, modified according to the taste of the end user. The relevancy of the concept of the

OPP in AM is that this technology is tool for giving a quick and fully customized response to the customer need, and thus 3D printing can appear at any stage of the supply chain. The highest costs of response are rendered to the engineer-to-order phase, while with 3D printing if the design needs to be adjusted, it can bring evident benefits to producers.

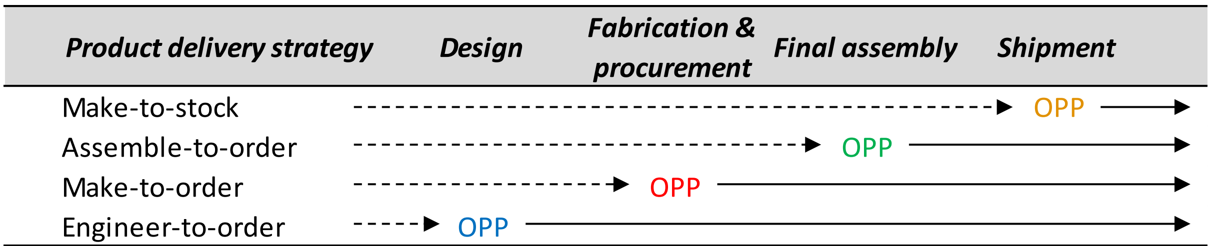

Figure 3: Illustration of the order penetration point based on Olhager (2003)

We could analyze Figure 3. in a way that if customization is needed in order to fulfil customer demand, the design phase has to be started. Fabrication would be the printing itself, while procurement is the phase for purchasing the 3D printing raw-materials. Final assembly is needed if several printed modules need to be assembled together. While shipping, as written above, does not necessarily need to happen from a central production facility, rather could be deployed close to the customer, if 3D printing service providers are available and the assembly service can be realized as well.

Overall, the geographical length of the whole product delivery procedure can be shortened, while reaction time can be boosted. In such a case, a classical supply chain would be redesigned, because suppliers are meant to be the local (close to the customer) raw-material, 3D printing service, assembly providers, and short-range logistics service providers.

According to a report by The Economist Intelligence Unit (EIU, 2018) by 2060 it is estimated that "such a shortening of supply chains could significantly disrupt the economy". However, geographical shortening does not necessarily bring reduction of complexity in the supply chain, as different types of suppliers would be needed, with a globally more fragmented production and logistics service providers. Contract management on a global-level with local partners, involving less frequent transactions might be affected, or might be a factor which will moderate an immediate, disruptive-type of change – and so as AM techniques are constantly being developed, supply chain consequences could be expected as incremental.

2.3) Digital inventories (inventories available immediately through production)

Inventories connect customer demands with production processes, therefore it is worth placing this sub-section between these two important stages of the supply chain. Broadly taken, inventories are piled up in order to bridge the temporal and geographical gaps in supply chains. Global supply chains are capitalizing on the economies of scale in the production in low-wage countries, and then ship the produced parts or finished goods to the destination countries. In a few examples, e.g. the car industry, local regulations can force car producers to provide the availability of their models even 15 years[1] after the production of that particular model ceased. However, in order to adapt to customer demand, and keep up with technological advancement, companies tend to refresh their models every now and again, and also come up with new models to penetrate into new markets – even if modular design permits that a car part can be built into several models.

Car producers need to operate large warehouses and keep parts on stocks. It requires capital from industry players to purchase the land, build the facilities, equip them storage space, machinery and required software, and also employ operators. If a car part is needed, it can be shipped from the warehouse. As certain models tend to the end of their life cycles (long after their production was ceased), the low inventory turnover of certain parts might trigger the consolidation of stocks into regional hubs.

The trade-off relationship in reaching a market in such a multi-tiered distribution model is between the reaction time and the operating costs. If physical inventories can be replaced by digital inventories, because a 3D printer can create the required part in an acceptable throughput time, the stock-keeping costs can be eliminated, and even warehouse capacities could be reduced. Getting rid of parts in inventories and not investing in facilities could free up cash in the company, and would reshape its supply chain activities. 3D printing service providers need to be involved in such cases, which might be challenging given the available equipment and the expertise. Such a redesigned physical supply chain can have inventories in digital formats, because the design of the part is needed only to be stored on servers.

[1] European Automobile Manufacturers Association
https://ec.europa.eu/DocsRoom/documents/10705/attachments/1/translations/en/renditions/native

2.4) Instead of producing parts, components are produced into finished products

Having discussed the impact of 3D printing on the inventories, the production or manufacturing phase needs to be analyzed along those factors, which might be important for the production processes, and post-production quality control activities.

During the design phase of 3D printed products, if subassemblies can be combined into a single component, a consolidation of parts could be achieved. The result would be the reduction of assembly time. If accompanied by supplier consolidation, and reduced number of items on inventories, costs could decrease, while productivity would increase, which are often regarded as trade-offs in production management – not in the case of AM application.

2.5) The cost (and time) of shifting production to a new series of product can be eliminated

The cost and time of shifting production to a new series of product can be reduced to a negligible level. Setting up the 3D printer to a new product means replacing the digitally stored files, and the printer can immediately start building up the item layer-by-layer. Modifying designs have the same amount of cost as in conventional production, still at least the shifts to another design are not penalized. Assembly lines try to distribute designing costs over high volumes of production, and not favour shifts in production – which can be ruled out by the application of AM technology. Shifts also bear risks, which is ruled out as well.

2.6) Impact on tools needed

Less tools are needed to assemble finished products from smaller amount of parts, when a product is created by a 3D printer, in contrast with a vast amount of aids, jigs, fixtures, and other tools which support assembly lines. Although, assembly lines are used for mass-production, where 3D printing still has a disadvantage compared to conventional production techniques. There is a particular use case for 3D printing in assembly lines: can foster innovation in a just-in-time environment. An on-site 3D printer can create the simplified tool used along the lines, e.g. where improvement from workers is encouraged and frequent. Instead of long supplier processes, a 3D printer can be faster and cheaper (once the machine is purchased).

According to Alexander (2015), “using 3D printing manufacturing aids ensures a high level of observable quality management, and helps maintain efficiency and profit”.

Firestone (2017) also stresses that 3D printing can replace some forms of tooling. Tooling inventories could be reduced, resulting in increased accuracy along assembly lines, and in a more controlled production process. The designated locations of certain tools spared could be freed up.

2.7) Quality management

In general, quality control (QC) of 3D printed products is costly, thus at a high-volume production economies of scale on QC can hardly be achieved with current AM technologies. Compared to conventional production, controlling the quality throughout the whole production process is difficult, labour-intensive, and inside complex structures could even be impossible. Multiple factors need to be controlled in order to achieve a certain quality-level, however in this case the benefits of operational flexibility of 3D printing might get lost, which would be the greatest advantage compared to conventional techniques.

2.8) Supply chain transformation

As with many new technologies when searching for business application possibilities, a lot of analyses emphasize that AM as well has the capability of transforming supply chains. Examples range from globally moved parts, which can be produced in low-cost countries, and now by the uses of AM production can be re-shored, or near-shored. However, AM requires inputs as well. Even if global material flow of products might decrease, the transportation of AM components might substitute the volumes.

Parts or product designs might require new computer aided designing platforms and specially skilled personnel, only because designs are transformed from 2D to 3D, supply chain transformations are not necessarily triggered. However, if product development cycles can be speeded up, the reaction capabilities to changing customer demands can be increased.

AM can hold certain benefits for changing the shape of supply chains, by reduced touchpoints (between partners), reduced inventories (for they become virtualized, especially for parts warehousing), less shipping might be needed in the supply chain, meaning that the exposure to physical supply chain disruptions can decrease, thus vulnerability can be decreased. The impact of some of these benefits might be tampered, since raw-material sourcing and shipping in is still needed for a supply chain applying AM, and more 3D printing technicians are needed on-site (or in flexible AM centres), which results in an exposure to the labour market.

Positioning the mentioned AM centres is also a decision point (or choosing suppliers with certain locations). If manufacturing hubs have 3D printing service providers, it might foster the creation of such AM centres.

3) Conclusion and further questions

The business perspective of the supply chain implications meant the adoption of the product-process matrix, and where 3D printing can be placed in it. Then in section 4) a rather qualitative analysis followed, connecting the physical features of AM with supply chain consequences.

As for further research, it would be worth analyzing the impact of AM in details on the items of the product-process matrix. Such an analysis could be backed by data gathered on the costs of 3D printers suitable for each combination. Already known fixed costs and variable costs of conventional production processes could be compared to the cost levels of industries embracing AM. If the data could be gathered for the past decades back to the 1980s when 3D printing appeared, and especially after the first desktop printer was commercialized in the mid-2000s, a prediction could be outlined for how the advancement of AM technologies has impacted supply chains.

Also, as for further research, the seminal paper of Spencer and Cox (1995) could be complemented with ‘what if’ scenarios, based on the implications mentioned in this working paper on supply chain layouts.

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