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Description of additive manufacturing and literature review

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DESCRIPTION OF ADDITIVE MANUFACTURING AND LITERATURE REVIEW

Abstract

Additive manufacturing (AM) technology holds several opportunities for production companies and supply chains delivering physical goods to their customers. Instead of discussing the technical details of this engineering challenge, this working paper focuses on the business potentials of the technology by briefly describing AM, and reviewing the relevant literature dealing with AM and supply chain management at the same time.

Keywords: additive manufacturing, production, literature review, supply chain management

AZ ADDITÍV TERMELÉS LEÍRÁSA ÉS IRODALOMFELDOLGOZÁS

Absztrakt

Az additív termelési (AM) technológia számos lehetőséget tartogat termelő vállalatok és ellátási láncok számára, amelyek fizikai termékeket állítanak elő végső fogyasztóik számára. A technológia mérnöki kihívásainak technikai részletezése helyett ez a műhelytanulmány a technológia üzleti lehetőségeire összpontosít, röviden körülítva az AM-et, és áttekintve az AM-hez kapcsolódó ellátási lánc menedzsment irodalmat.

Kulcsszavak: additív termelés, gyártás, irodalomfeldolgozás, ellátási lánc menedzsment

Contents

1) Introduction

Additive manufacturing (AM) technology, or three-dimensional (3D) printing as a physically feasible form of production was first conceived in the 1980s. Since then, it has progressed to an applied tool in various industries, and it is predicted to transform manufacturing and supply chains by 2050 to a great extent.

The essence of AM, in contrast with conventional manufacturing, is that the product is not extracted, cut, or carved from its original form into a desired form, neither created by injection moulding where a mould is used, but a printing machine is building up the product layer-by-layer. There is no need for cutting, for the printer only builds until the edges. There is no need for carving or drilling, because the printer leaves those spaces out during the manufacturing process. There is no need for negative moulds, because the printer creates the product in the same shape as it would be determined by the container.

All these characteristics result in a reduced amount of raw-materials needed for the production and a lower weight of the product, while sustaining the required stability and endurance features of the created structures. The cost structure and the performance of the final product of certain industries rely on such improvements, e.g. airlines, automotive industry.

Even if this manufacturing technology can be defined in a concise way as above, currently there are seven main types of AM, and engineers are constantly researching the field of 3D printing to reach a mass production breakthrough. Rather than focusing on the technicalities of AM, this paper is attempting to map the effects of AM technology on supply chains, and provide tools for evaluating the consequences of 3D printing on manufacturing and logistics systems from a business perspective.

The business structure of manufacturing could be transformed into a hybrid one where conventional manufacturing is complemented with AM features based on economics, and also distributed manufacturing can occur as a new form of suppliers, meaning that firms specialized on 3D printing can work in a symbiosis with multiple production companies in order to deliver flexible solutions, while keeping economies of scale as a result of highly utilized printers, and skilled technicians.

Global supply chains might transform from benefiting from partially outsourced production to low-wage countries into shorter and more reactive supply chains benefiting from geographical proximity and flexibility of no-cost and immediate change-overs of produced parts, keeping suppliers close to the final stage of assembly, and to customers.

2) Additive manufacturing description

According to the ASTM International, as a standard terminology, AM is: "a process of joining materials to make objects from 3D model data, usually layer upon layer, as opposed to subtractive manufacturing methodologies. Synonyms: additive fabrication, additive processes, additive techniques, additive layer manufacturing, layer manufacturing, and freeform fabrication.", whereas 3D printing is a distinct concept, meaning "the fabrication of object through the deposition of a material using a print head, nozzle, or another printer technology.".

Since subtractive manufacturing appeared in the previous definition, it is needed to be broken down to its elements, defined also along ASTM, "making objects by removing of material (for example, milling, drilling, grinding, carving etc.) from a bulk solid to leave a desired shape, as opposed to additive manufacturing.".

Sometimes, subtractive manufacturing is also known as extractive manufacturing, which would mean cutting away at raw-materials, or drilling into the semi-finished product (creating holes for pipes, wires, screws).

As already used in the introduction of this paper, AM and 3D printing are going to be used as synonyms. Also, extractive and subtractive manufacturing will be used as synonyms.

Another technique of creating a one-piece part is moulding, which means injecting metal or plastic into pre-made moulds, by which the products take up the predefined shape. After creating the required shape, cutting away might also can be needed to remove the edges, which will not be used anymore, and can be thrown away as scraps to be recycled.

Without going into technical details, there are seven main categories[1] of AM:

- material jetting: like an inkjet printer on a sheet of paper, material is deposited in drops, and then solidifies;
- vat photopolymerization: a vat of liquid photopolymer resin is used, and the model is constructed layer-by-layer out of it;
- material extrusion: material is drawn through a nozzle, heated, and deposited in a continuous stream (trademark of Stratasys company);
- directed energy deposition: like material extrusion, only the nozzle can move more freely;
- binder jetting: an adhesive is deposited on powdered material, and alternating layers come on top of each other;
- powder bed fusion: mainly for metals, laser beam is used to melt material;
- sheet lamination: sheets are stick together, and then cutting is used to get the required shape;

Three main types of raw-materials can be used in AM: polymers, metals, and ceramics – the above mentioned seven processes use these materials.

The product creation happens in one printing process, therefore organic shapes can be produced, after which there is no need for extraction, reduction, drilling, or waste elimination. Only what is needed is produced by the 3D printing machine.

A 3D model of the object to be printed needs to be created. Digital files contain the designs of products, and the instructions on how those products need to be constructed layer-by-layer, because the design contains the product digitally sliced by layers.

3) Literature review

The literature review of AM was conducted by reviewing the relevant academic journal articles and books. Relevant means that this case is when an article deals with both AM and supply chain management. Since this paper is about to analyze the business impact of AM on supply chains,

[1] https://www.lboro.ac.uk/research/amrg/about/the7categoriesofadditivemanufacturing/

articles covering AM from technological point of view were not considered. The number of academic papers proved to be limited, therefore the literature review is extended by publications of industry and business professionals, which analyzed AM particularly from economic and business perspectives.

Liu et al. (2013) with a focus on aircraft spare parts industry analyzed the potential improvements AM can bring to supply chain dynamics, shipping costs and delivery lead times. They provided approaches to configure this particular supply chain using AM technology, and evaluated AM based on supply chain operations reference (SCOR) model. Their investigated three scenarios are interesting in particular: total safety inventory in a conventional supply chain (not much impacted by AM), a centralized AM supply chain, and a distributed AM supply chain. Quantitative analysis was conducted for all three scenarios, and the results were plotted for comparison. The study concludes that a centralized AM supply chain is more suitable for parts low average demand, with relatively high demand fluctuation, and long manufacturing lead time. The distributed AM supply chain fits for parts with high and stable average demand, especially when reaction time to demand needs to be quick.

Khajavi et al. (2014) evaluated the potential impact of AM improvements on the configuration of spare parts supply chains in general. Conclusions are drawn from the aeronautics industry case they analyzed. The preferable supply chain configuration was the centralized production using AM, owing to the high purchase price of AM machines, and the personnel intensiveness of the technology. Distributed spare parts production can also be useful once 3D printers become "less capital intensive, more autonomous and offer shorter production cycles".

Mellor et al. (2014) focus on the implementation process of AM, as it is a production technique capable of serving business needs. The trigger for the increased research effort and industrial application of AM is that several globally active companies, which outsourced their mass production to low-cost countries, are forced by market demand to switch toward more innovative and customized products, mainly in lower volumes.

Bozarth and Handfield (2016) in the 4th edition of their classical operations and supply chain management book dedicated a chapter to process choice for production and supply chain operations. Beyond the basic manufacturing processes of the product-process matrix, hybrid manufacturing processes are detailed as well. (The 5th edition is to be published in 2019, according to the currently available table of contents will contain AM processes as well.) What is relevant in this paper, regarding AM, is that “hybrid manufacturing processes seek to combine the characteristics, and hence advantages, of more than one of the classic processes”. This could be considered as a forward-looking thought, for when 3D printing is combined with the classical processes, certain basic characteristics of industry processes might be overthrown. We elaborate on this later in Section 4.

Handfield and Linton (2017) covered in their book up-to-date topics affecting supply chains. Among these we can find autonomous vehicles, 3D printing, nanotechnology, robotics, artificial intelligence, internet of things, and quantum computing. According to their estimation, a whole series of industries will be transformed, including production, warehousing, distribution, and supply chains. Their prediction is that advancement in new technologies will not eliminate supply chains, will rather “morph” them, as organic matter or plastics will be the raw-materials of 3D printing. It is a rather original insight that “countries with no resources can become transshipment points that smooth out supply chains”, referring to the centralized-distributed options of AM technology deployment in supply chains, being analyzed later in this working paper.

Customer demand is also needed to be addressed with increased flexibility and faster reaction time. As AM technology can serve such business requirements, this research provides an implementation framework on how to adopt the technology, to produce high value products and generate new business opportunities. Among their results we can find that 3D printing raw-material suppliers are limited for a predetermined grade used in certain machines, and prices are still high – in most cases prototyping is not moved to mass production phase. Reliance on machine suppliers in terms of R&D activity is also an issue.

The location of manufacture in most cases remain centralized, which in global supply chains’ term is not a leap forward for flexible and rapid customer supply. A single case study was used in the paper, which is a limitation for external validity, still several challenges with AM implementation were identified in their paper, which might be generalized later on. As a closing message, the authors consider AM as a disruptive technology – which is challenged by this working paper based on the following ideas.

The word ‘disruptive’ if used in the sense as it was introduced by Christensen (1997) and was once-again revisited by Christensen et al. (2015), then AM might shake up supply chains, however most probably will not disrupt them, because 3D printing will be built into supply chain processes – the shape of business networks might change, while the principles on how to conduct business, how to handle supplier-vendor relations, will remain the same. One key argument against the disruptive nature of AM is that 3D printing requires more resources (in terms of investment into the machinery and broadly skilled technicians), not less. Thus small-sized would-be entrants to the market cannot start with a lower performance, and then later on push out incumbents, and become mainstream – and the push-out will not work in part owing to being only one supplier in a supply chain with AM capabilities. Because of the resource intensity AM implementation is accompanied by, the amount of 3D printing service provides remains low, and does not reach a magnitude which could push out incumbents.

Therefore, the whole chain cannot be disrupted. At most some suppliers could be if they refuse to adopt new technologies. As the EIU study (2018) discusses, the central firm of the supply chain tries to drive its suppliers into 3D printing, in order for the whole chain to deliver superior performance to its customers (in their examples, Deutsche Bahn, Airbus).

The following table sums up the literature covered above:

Author(s)	**Year**	**Essence**
Liu et al.	2013	Quantitative analysis was done on three aircraft spare parts industry supply chain configurations in search for the benefits of AM. No AM, centralized, and distributed structures were compared along multiple factors.
Khajavi et al.	2014	Analysis on spare parts supply chain. The utility of a distributed production can be viable once the cost side of 3D printing is lowered.
Mellor et al.	2014	During the implementation of AM, a niche market is recommended to be found, where there is need for innovative and customized products in low volumes.
Bozarth and Handfield	2016	A book on operations and supply chain management, where among the basic manufacturing processes of the product-process matrix we can find hybrid manufacturing and AM as well.
Handfield and Linton	2017	Dealing with new technologies in supply chains. 3D printing is predicted to be an opportunity for countries without resources by including them(selves) in global supply chains as transshipment points.

4) Conclusion and further research

This working paper attempted to analyze the impact of AM on supply chains from a business perspective. After a basic technical description was provided for AM technologies, the paper uncovered the relevant supply chain literature.

As for further research, it would be worth analyzing how AM affects supply chain processes, their efficiency, and the financial benefits that the technology can bring to businesses which embrace it.

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