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Impacts of Additive Manufacturing in Value Creation System

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Abstract

Nowadays, additive manufacturing (AM) reveal changes in the entire value creation models, strategies, systems and processes. Evidently, AM involve changes internal and external to companies e.g. on time to market strategies, product variety and customer satisfaction. The objective of this paper is to examine the impact of additive manufacturing on companies value creation, in which the focus is on single areas. To this end, we identify the relations between the utilized potentials and challenges, value creation processes and associated impacts. Analyzing this complex correlation and measuring the effects is demonstrated and identified, respectively, in a use-case study.

Keywords: Value creation system; systematic identification; additive manufacturing; technology potentials, technology impact

1. Introduction

Additive manufacturing technologies (AMT) became more and more relevance in industrial environment in the recent years [1]. The main target for companies in using new manufacturing technology is to generate an added value for the customers and raise the process efficiency in the whole value creation system [2,3]. The value creation system is not only including production and logistic processes, but also it represents the point of view how a company organization creates, sells, and delivers products [4].

Despite technological impacts, additive manufacturing has an extensive influence on the business process and derives a completely change in adding value and the processes [5, 6, 7]. With AMT, the added value is mainly generated in the product design and use phases, whereas the manufacturing processes. Continuous improvements, like higher building speed, better reliability or higher accuracy enable the establishment of additive manufacturing (AM) in more fields of application [8]. By considering these aspects, AMT are relevant enabler for smart and flexible value creation systems [9]. Beside AM potentials and its positive effects to value creation systems, AM integration also causes serious changes with partially negative effects in structures of value creation systems [9–11].

This paper aims to examine the impact of AMT and the effects on the whole value creation system, based on technology potentials on the one side and challenges of AMT implementation on the other side (see Section 2.2). Due to the fact, that AM has the potential to revolutionize whole structures of supply chains [10,11], it is necessary to consider changes in the whole value creation system, especially for identifying effects on the customer or delivery site [12]. The challenges by the identification of impacts in the value creation system are namely the individual, use case specific impacts as well as the complex relations between the value creation processes. These circumstances make a use case specific analysis necessary [13]. Considering the methodological approach described in Section 3, the result is a holistic framework for examining impacts and identifying interactions as a broad basis for further technology evaluation (see Section 4). Big effects are caused in identifying new additive application cases in companies. A subsequent technology assessment and an evaluation of technology potentials in an early technology implementation phase needs to be encouraged.

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Known as rapid prototyping technologies, AM today is an integral part of industrial production like tooling, functional parts, serial parts or spare parts [16]. For this reason, not only the additive manufactured product is in focus, but also the whole value creation system. From this point of view, it is demanded to produce in an efficient way and to be able to tap the full potential of additive technologies. Individual topics of investigation are e.g. individualized or simulation based optimized products, added customer value based on function oriented product development, new business models based on a digital value creation chain etc. In the following chapters, the relevant aspects regarding AM in industrial production will be explained.

The focus of the developed approach is on the “Direct Manufacturing” and “Direct Tooling” sector of Additive Manufacturing. This includes the fabrication of end-user products, especially the production of final products as functional models, in small series or series production, of tools and auxiliary tools as well as mold making [14]. This field of observation can be separated into the following divisions [15]:

- Direct Manufacturing: Production of marketable primary products, which fulfils the technological and mechanical requirements of end-products
- Direct Tooling: Manufacturing of serial applicable tools respectively tooling inserts
- Rapid Tooling: is a Vertical cross-sectional area of prototype tooling and direct tooling. The challenges are to find tradeoffs concerning cycle time, size accuracy, material, price et cetera.

2. Potentials and challenges of AM in the value creation

In the following sections firstly the AM specific VCS and secondly the potentials and challenges regarding the whole VCS are described.

2.1. AM value creation system

A VCS is a set of activities creating value for customers carried out by economic players using sets of human, tangible and intangible resources [16].

In this paper, we define the VCS and its activities from the perspective of AM as shown in Fig. 1 and depicted in Table 1.

The selection of end-user products, manufacturable by AMT is based on technology substitutive approaches in most cases, neglecting the possible potentials in the residual value creation chain [17]. Beside the material and quality related properties, more details in the VCS must be taken into account (e.g. process stability, productivity, degree of automation, post processing, flexibility and decentralization of production, the product life cycle as well as the degree of implementation of additive technologies [18]) to realize additional potentials [13,19–21]. Furthermore, this broader view enables an AMT technology-based development of economic business models [22].

The framework of the VCS consists of six main processes as shown in Fig. 1. It maps the concrete material flow from the supplier through the manufacturing process and support processes to the customer [23]. Further aspects are the product development and the product lifecycle process, which have been taken into consideration too. That expands the observation field to the innovation and product lifecycle view.

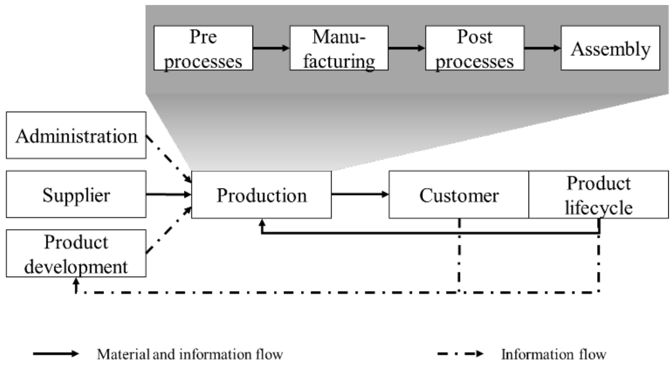

Fig. 1. The AM value creation system

Table 1. The value creation system processes

Main process	Sub processes
Product development	product design, product engineering, technology selection and material selection
Supplier	raw material production and distribution
Administration	product planning and control, human resource, quality management, work safety and IT
Production	manufacturing in the additive machine, pre- and post-processing (maintenance, intralogistics, demoulding, heat treatment, etc.), part assembly and inbound logistic
Customer	use of the end product and interaction between customer and product development
Product lifecycle	start-up phase, use phase, spare parts management and recycling

2.2. Potentials and challenges of AM

The application of AM technologies generates added value (potentials) in different areas (investigation fields). However, due to necessary changes in the VCS, may incur disadvantages or process or product adaptations, resulting in additional expenses (challenges). Table 2 gives a description of the fields of investigation with respect to potentials and challenges, which influence the AM VCS.

Table 2. Fields of investigation

Field of investigation	Potentials and Challenges
Product	• … due to the mostly necessary or currently possible changes in product design
Technology	• … due to the layered construction dependent characteristics in the view of the technical manufacturing process • … due to technological restrictions which might be changed as a result of ongoing research and rising technology readiness level of the additive manufacturing machines

Field of investigation	Potentials and Challenges
Process	• … due to the influenced pre- and post-processes of the AM production process (excluding manufacturing processes)
Value chain	• … due to technology specificity which have influences the whole VCS and future business models.

For further consideration of the effects on the VCS, this categorization adds value in terms of clarity and general awareness of the interactions among the investigation fields and VCS processes. By means of a comprehensive literature research and an analysis of use cases, the key potentials and key challenges of AM have been identified. (see Table 3). Not only manufacturing process improving potentials has been taken into consideration, but also the entire VCS was considered. In addition, key potentials and challenges that are generated in the specific fields of investigation that specifically related to AM have been derived. These key potentials and challenges are the starting point for the analysis of the impacts used in a use case study.

Table 3. Key potentials and key challenges of AM (potentials adapted from [20,22,24,25], challenges adapted from [25–31])

Field of investigation	Key potentials	Key challenges
Product	• Individual and complex geometries • Performance-enhancing geometries	• Product quality • Manufacturing driven design
Technology	• Material-efficient manufacturing • Tool-less manufacturing	• General technical restrictions (Manufacturing speed and Build volume) • Reproducibility • Material availability • Implementation effort
Process	• Production-process-performance-enhancing geometries	• Process automation
Value chain	• Digitalization of value chain • Shift of value creation	• Digitalization of value chain • Value creation structures (current)

3. Methodology

The use cases has been identified through reviews of reports from technology providers (e.g. EOS, Lithoz), workshops with participating companies in the funded projects "AddManu" and "Emerge" and through consultation with industry and domain experts. The focus was only on successfully implemented use cases in the industrial production areas, namely, direct manufacturing and direct tooling.

The selected use cases have to be seen as a current snapshot of additive manufacturing in industrial production.

Each use case was described in a uniformly structured format (see Section 3.1) and analysed regarding to the impacts of AM on the VCS. The ambiguous results concerning the identification of impacts and the assignment to the VCS processes was counteracted by comparing each individual use case with the others.

The identified impacts were then assigned to the well-known potentials and challenges of AM (see Table 3) as well as the fields of investigation (see Table 2). Table 4 lists an extract of the identified and categorized impacts, the complete list is available at [32].

The method for identifying and assigning the effects as well as the definition of a use case are described in more detail in the following sections.

3.1. Use case definition

To be able to identify substantial potentials and efforts, caused by implementing additive manufacturing technologies, a wide basis of relevant data is necessary. In order to create a generic approach, the main challenge is to identify different relevant input factors and their systematic categorization. Therefore, a basic structure of a use case has been developed, where different levels like general data, input parameter and potentials/effects were defined (see Fig. 2).

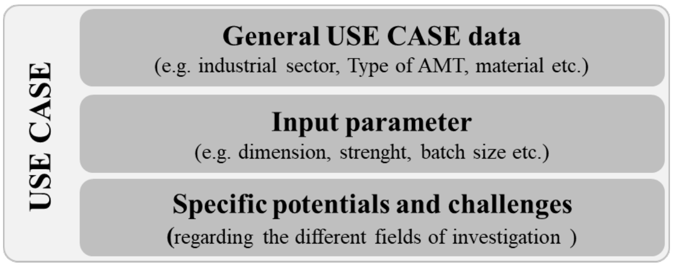

Fig. 2. Definition of use case structure

The necessary data for the description of the use cases in the above-mentioned structure has been extracted from the original use case sources. Furthermore, the identification of the specific impacts in the VCS has been done by the board of experts. A list of all considered use cases in this research is available at [33].

Based on this use case structure, an aggregation of the different impacts can be carried out which is then mapped to a generic structure of potentials and challenges shown in Table 3.

3.2. Identification and assignement of impacts

In total, 54 use cases from five different industries (aerospace, medicine, mechanical engineering, consumer and automotive) have been taken into account.

Each use case has been systematically analyzed by the board of experts with regard to its impacts in the VCS. In the next step each impact of this specific use case has been assigned to the VCS-main-process where he occurs as well as the potential/challenge he belongs. Companies often only communicate the positive, marketing relevant impacts of AM to the value creation. Therefore, the identification of the challenges and negative effects has been supplemented by a literature research.

Fig. 3 demonstrates the impact identification procedure in a conceptual form for a specific use case from the mechanical engineering industry and further shows an excerpt of the identified impacts.

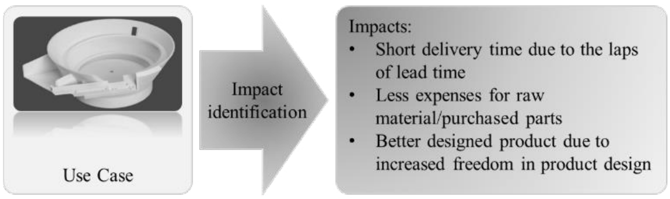

Fig. 3. Identification of impacts from a specific use case in the mechanical engineering industry [33]

Each impact is always assigned to at least a potential or a challenge as well as to a VCS-main-process. This assignment can be seen in Fig. 4. It shows how the categorization has been made for the use case of Fig. 3. The arrows in the figure represent the potentials to which the impact has been assigned.

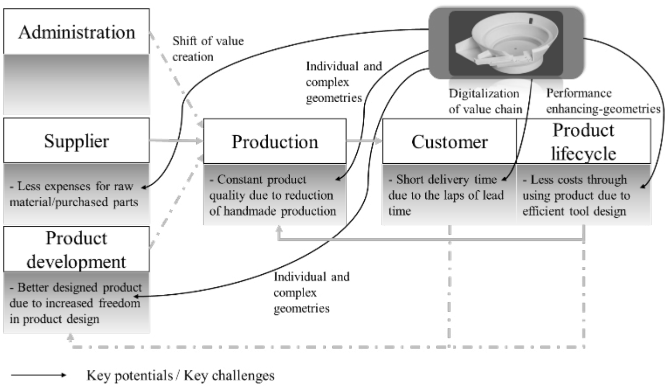

Fig. 4. Assignment of the identified impacts

4. Results - Impacts from AM to the value creation system

The systematical procedure outlined in Section 3.2 has been applied for all 54 use cases. Notably, the focus of the analysis has not been on identifying the frequencies with which the impacts occur. But rather the aim was to give a possible holistic overview of all possible impacts due to AM. However, double or equivalent impacts have been cumulated. In order to be able to analyse the frequency and give a valid statement, more use cases have to be taken into consideration. Due to the novelty of this technology, as already mentioned above this can only be a snapshot of the current situation. Therefore, the focus was on the identification and assignment of all occurring impacts.

As can be seen in Fig. 5, multiple arrows point to a VCS process which reveal potentials that can have an impact on a VCS process and vice versa.

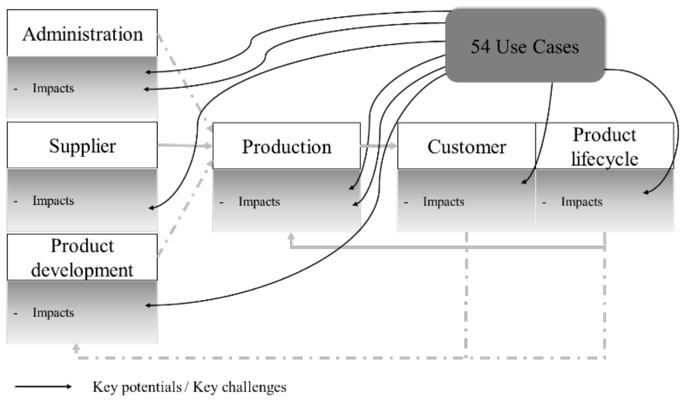

Fig. 5. Assignment of all in the use case analysis identified impacts

The categorizations and systematic use case research in the industries and applications described in the previous sections have resulted in the two tables as shown in Table 4 and earlier work of the authors [32]. The Tables in [32] represent on the one hand the sum of all the possible emerging impacts by integrating AM in the production system and on the other hand the concrete assignment of impacts to the different areas of the VCS categorized by their generating potentials or challenges.

Table 4. Impacts to the VCS by AM (excerpt)

Field of investigation	Key potential / Key challenges	Impacts to the VCS	Product development	Administration	Supplier	Manufacturing	Customer	Product lifecycle
Product	Product quality	– Limited strength and resistance to heat etc.	x				x	x
	Performance enhancing geometries	+ Durable product due to optimized geometry					x	x
		+ Increased comfort because of a flexible and adaptable product					x	
	Manufacturing driven design	– Lack of formal standards		x				
Technology	Material availability	– Limitations on materials	x					
Process	Production process	+ Reduced amount of components due to integration of assembly	x			x		
Value Chain	Digitalization of value chain	+ Reduced excess production due to production on demand				x		
		+ Short delivery time due to the lapse of lead time					x	

Especially interesting are the interactions between the individual effects and the areas of observation. The mutual influence of the individual effects ranges from very large to no dependency. As a good example of strong interaction, the impact of "Limitations on materials" in the Technology and Product Development area relates to the impact of "Limited strength and resistance to heat etc." in the Product and Customer area. These two effects are fundamentally strong and both benefit from further developments in the area of material availability.

Important is the fact that the identified impacts relate to the current state of the art of additive manufacturing technology. In the future, there will be many improvements in terms of larger build spaces, higher production speeds, etc., and will influence the hitherto identified negative effects of additive manufacturing on the VCS [34]. For a further consideration of the effects, it is therefore necessary to consider the technology readiness level of the individual technologies based on the specified use case [23].

The result of this paper serves as the basis for the further systematic consideration and analysis of applications of additive manufacturing. This makes it possible to evaluate the suitability of potential use cases and to analyze the effects of additive manufacturing on the current situation of production companies.

5. Outlook

The developed approach offers a broad basis for many further research activities regarding implementation, assessment and evaluation of additive manufacturing technologies as an element in an entire VCS and the validation of their potentials. Based on the results, the quantification of the identified impacts, which serves as a basis for an economic and technical feasibility study, is to be explored and further is a transfer of these results into an assessment tool for potential use cases aimed. The assessment tool is intended to provide potential users of AM with the opportunity to analyze the suitability and the effects to the VCS of a specific use case.

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