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Additive Manufacturing – enabling technology for lifecycle oriented value-increase or value-decrease

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Abstract

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Keywords:

1. Introduction

The Internet has radically altered the proposition that listening to your customers can help you improve your products and services. Customers are now able to be so intimately involved in the development and usage of what you have to sell that they can become co-creators of value. Co-creation adds a new dynamic to the producer/customer relationship by engaging customers directly in the production or distribution of value. Customers, in other words, can get involved at just about any stage of the value chain. Some managers liken the transformation to turning customers into "employees." Consequently, managers must learn new techniques to motivate customers to co-create value as well as ways to successfully monitor and manage the process along the way.

Additive Manufacturing (AM) seems to have the potential to substitute traditional manufacturing technologies in different branches [1]. The effects thereby are that the "printing" of AM-Parts is location-independent, time-independent, scalable (down to batch sizes of one) and almost know-how independent [2, 8]. In addition to the Open Innovation approach, AM enables the customer to become a manufacturing partner with relevant impact on the value creation network [3, 9].

So far, customized products are manufactured with different procedures. The current development of fabrication methods shows that 3D printing gets increasingly established [4]. Many individualizable products can already be produced via 3D printing methods; not only on the level of consumer goods like cell phone cases but also on the level of medical equipment goods like personalized hearing aids, fitting to the individual ear shape [5, 6].

Due to these trends in consumer behavior and technology, 3D printing of individualizable mass products offers potential for new business concepts [7] – but it seems also to have the potential for loosing creation of value because of the ability to easy print respective to copy parts.

The focus of this paper is the use of AM in industrial businesses. As mentioned above, industrial goods are also more and more customer individual. Therefore industrial businesses have to figure out how they can benefit by using AM for individualization purposes. In addition, AM seems to have potential to improve the efficiency of spare part logistics by printing spare parts at the location of use. But thereby they also have to consider with respect to their business models keeping service and maintenance far from printing spare parts by the user themselves.

2. Research Question and Research Design

Assuming that especially within Mass Customization scenarios industrial goods are not printed completely but rather individual parts are manufactured additively, manufacturers have to decide on which level of the bill of material (BOM) the AM-parts can be placed to fulfill both:

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enable customers to print low value spare parts by themselves but also to prohibit losing business relevant maintenance activities.

Therefore the approach described in this paper aims at answering the following questions:

What is the influence of manufacturing in the value chain during the whole product life cycle and on which level of the BOM have AM-parts to be placed to increase value best possible?

Based on literature work, an in depth case study was carried out within a medium sized industrial company to capture the product lifecycle and facets of customer individualization within industrial goods. The company itself is a typical SME and is developing and producing medical equipment like lighting for operation rooms at one location in the southern part of Germany. The products are sold worldwide. The service and maintenance is also delivered from the location in Germany. Within the case study, two scenarios are derived. With the aid of the scenarios a concept is deduced which considers the potential of AM with respect to mass customization as well as value increasing.

3. Mass Customization and Additive Manufacturing

The most fundamental principle of low-cost, high-volume mass customization is modularity, which enables the supplier to do only and exactly what each customer needs. Not only the product should be modular, the supporting processes also should be able to retain the modularity till the end when a customer exercises his choice. In mass-individualization, new product design and -development is fully linked to the concurrent design of the related business processes. Managing business processes and product-service systems through life-cyle in many cases is just possible within collaborative networks.

For realizing the benefits of Mass Customization, companies usually start from its product design by introducing a common platform. Platform-based approach enables a number of product variants to be developed from a common platform, which can largely reduce the time and cost of new product development. Platform commonality means to standardize and share components among products.

Within this concept, the role of the customer is a passive one: he can only make his choice/customization out of the predefined options of the manufacturer. The predeveloped options are generated by following strict design rules (e.g. DFMA - Design for Manufacturing and Assembly) in order to achieve the cost-saving and time-saving effects for the manufacturer.

Parallely to the product module or plattform strategy, the corresponding manufacturing and assembly processes are also designed in modules. The principle is to postpone the socalled “Order Penetration Point” as late as possible in the value stream – this will result in a postponement of the time- and cost-consuming customized processes towards the end of the value chain. As a result, manufacturers produce a generic product and become more flexible and responsive to customer demand.

Within this concept, the customer usually is not at all involved – only the partners of the predefined supply chain of the manufacturer take influence on the processes and on the position of the OPP.

By using the AM technology, the “classical” Product-Development-Process (PDP) can be enlarged in two directions:

- Towards the Front-End-Process (FEP) where the design concept of product and processes takes place: the customer becomes active member of the product design team by generating the final geometrical dimensions of the product by himself.
- Towards the Back-End-Process (BEP) where the production from the early beginning of the product lifetime until the final usage takes place: the customer can become active member of the supply chain network by overtaking the manufacturing of product components with AM by himself.

<table>
<tr><th>new: FEP</th><th rowspan="5">SOD (start of development)</th><th>old: PDP</th><th rowspan="5">SOP (start of production)</th><th>new: BEP</th></tr>
<tr><td>Customer interface</td><td>Requirements Engineering internal value chain</td><td>new business model</td></tr>
<tr><td>Active product configuration</td><td>modular based product configuration modular based process configuration</td><td>Integrated process configuration</td></tr>
<tr><td>Community innovation (Open Inno 2.0)</td><td>Open Innovation Lean Production</td><td>Collaboration Network (Industry 4.0)</td></tr>
<tr><td>Design for Additive Manufacturing</td><td>Design for Manufacturing Design for Value stream</td><td>Design for Value Network</td></tr>
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Table 1: FEP, PDP and BEP

4. Use Case scenarios

The use case under consideration is - as mentioned above - a manufacturer of medical equipment. Initial point of the use case is, that a new product design for a carriage arm was necessary in order to realize the different customer variants more cost efficiently. The carriage arm has to be individualized in geometry, for example with a logo of the clinic or the name of the company. Within the use case, two scenarios of MC with respect to AM are derived: scenario 1 - value decrease and scenario 2 – value increase.

4.1. Scenario 1 - value decrease

In Scenario 1, the carriage arm was designed on the basis of a platform, the individual design should be realized by customized components. For efficient production of the variants, the customized components should be assembled as late as possible – *even* by the customer.

In the first step, the individualization was concentrated into the cover cap of the link between the carriage arms (c.f. figure 1). Production of the cover cap was planned to be done via classic injection moulding which requires special tools for each component. This was too expensive due to small production quantities for each cover cap.

In the next step, the cover cap was designed in order to be produced by Additive Manufacturing processes – either by an external AM-producer or by the customer itself who received all the necessary 3D-data by the medical equipment company. (Design for Additive Manufacturing).

The calculation of the variants costs for the cover cap revealed a severe cost increase (more than 10%) in relation to the cover cap due to the high investment cost for the tooling (high costs per part due to small numbers).

Therefore the decision was made to leave the manufacturing of the cover cap to the customer by using 3D-printing. Therefore, e.g. in case of maintenance or just in case of changing the design, the manufacturing company is not necessarily involved. This leads to the assumption, that in this scenario the value for the manufacturing company is decreased by AM.

Nevertheless, this scenario seems to be attractive for the manufacturing company in some cases:

- Maintenance of the part isn't part of the business model
- Spare part delivery to worldwide locations have to be cheap and fast
- Part isn't critical for product functionality and/or security aspects.

Considering the BOM, in this scenario the carriage arm has four levels in which the customer individual part is placed in the next level to the product. If WP 3 is designed for easy assembly, the customer can design, print and assemble the product by himself.

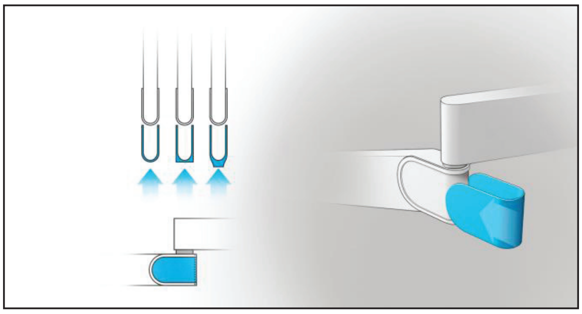

Figure 1: Cover cap within scenario 1

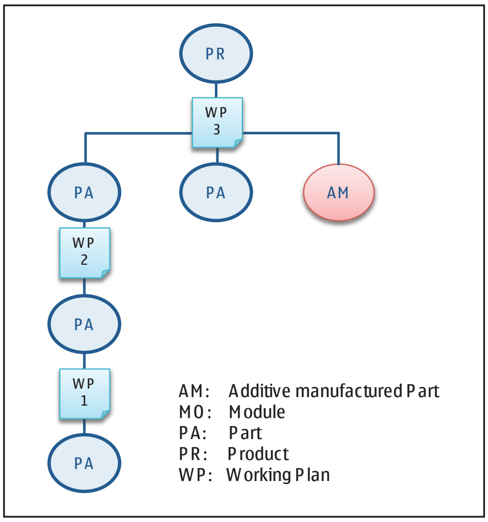

Figure 2: BOM within scenario 1

4.2. Scenario 2 - value increase

Scenario 2 shows a configuration in which the AM-part is part of a module. Thereby the customer may design the part individually, but the company will retain printing and assembly through a complex WP 2 – even in case of maintenance.

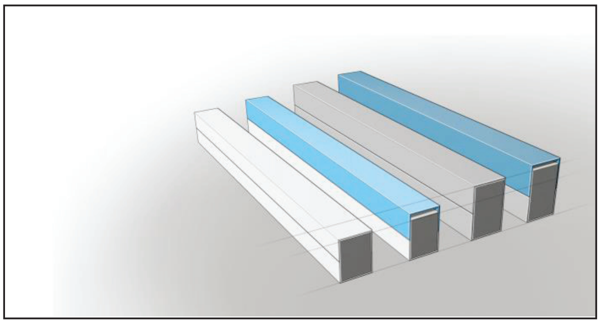

Figure 3: Cover cap within scenario 2

Hereby the alu-profile is a module which includes the customer-specific spindle and the wiring harness: the variation parameter are length and diameter. Using classic manufacturing processes, a BOM and working plan would be necessary to realize all the different variants; the process costs for this solution is much more higher as the additional price the customer is willing to pay (<5%).

With AM the alu-profile can be manufactured directly from the CAD-data and therefore save the additional cost for the manufacturer.

Considering the BOM, in this scenario the carriage arm has also four levels in which the customer individual part is placed within a module at least in the second level under the product. If WP 2 is designed for assembly through the manufacturing company, the customer can design, but not print and assemble the product by himself.

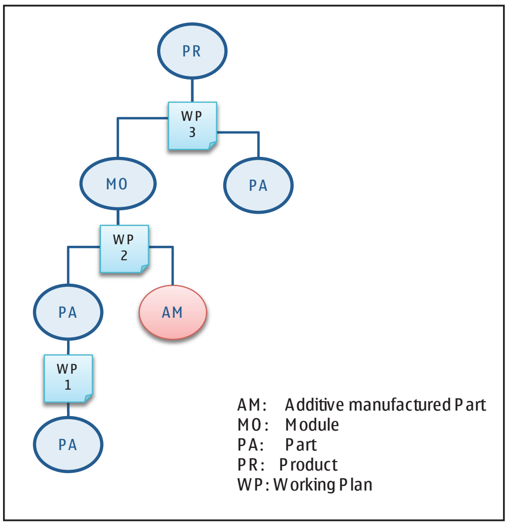

Figure 4: BOM within scenario 2

Therefore, e.g. in case of maintenance or just in case of changing the design, the manufacturing company has to be involved. This leads to the assumption, that in this scenario the value for the manufacturing company is increasing by AM.

This scenario seems to be attractive for the manufacturing company especially when:

- Maintenance is part of the business model
- The part is critical for product functionality and/or concerns security aspects.

5. Manufacturing engineering concepts

Wrapping up both use case scenarios, AM enables MC in an economically way. But as the scenarios have showed, it isn't just replacing traditional machinery tools by 3D printers. It is primarily creating new business models (BEP) and front end processes (FEP) linked with adapting the structure of products with respect to the part list and working plans.

In scenario 1 the customer individual part is placed in the next level to the product. If WP 3 is designed for easy assembly, the customer can design, print and assemble the product (e.g. in case of maintenance) by himself.

Scenario 2 shows a configuration in which the AM-part is part of a module. Thereby the customer may design the part individually, but the company will retain printing and assembly through a complex WP 2 – even in case of maintenance.

Therefore, in the following two manufacturing engineering concepts are introduced which support the two identified scenarios.

5.1. Manufacturing engineering concept for value increasing: direct involvement of the customer into the product design process

Rule-based product configuration usually aims at providing sales and production in handling products with many variants. As mentioned above, analysis of the configuration process illustrated the requirement for a new configuration guideline in order to enable 3D manipulations to the customer in a simple way. Within the project MAC4U, the software partner changed the compilation of formal description- and configuration rules to the definition and implementation of configuration items, i.e. instead of configuration rules, concrete configuration items were defined. These configuration items and the actual 3D-model compose a common data set; each configuration item consists of a generic and a format specific part, whereas the type of the configuration item determines which attributes are contained in both parts.

Thereby, the customer with no advanced technical knowledge can configure his personal design of the product by using a simple graphic-based user interface within the limits of a preset configuration space in 3D.

This will result in an active configuration performed by the customer himself who is directly involved into the design process of his own product.

The manufacturer also changes its role by only configuring functional modules and not the complete geometrical design any more.

This concept will lead to a complete *change of the "mind-set" concerning how to build up the product architecture* and therefore the corresponding documents as e.g. the BOM:

Without the use of AM, a structured hierarchic product design is necessary: starting from the specification of the product, functionalities of components and modules are developed and the product structure is generated adequately (multilevel BOM).

In strong relation to the BOM, a sequential process structure beginning with prefabrication, completion, pre-assembly, final assembly to the product is developed (assembly BOM)

With the use of AM, only defined solution spaces are determined based on function modules (3D-model); the final design is accomplished by the customer.

Concerning the development of the process chain, this is reduced just to the transfer of a data package (e.g. STL-data) from the 3D-modell to the 3D-printer. What remains for the user of the 3D-printer is the know-how about the performance parameters (e.g. geometrical limitations, process time etc.).

This concept will create *additional value* for the manufacturer due to the individualizing components for the customer.

5.2 Manufacturing engineering concept for value decreasing direct involvement of the customer into the value creation process

AM enables the customer to overtake the role of a manufacturing partner within the existing value network of the OEM – e.g. for producing a component of the product in the case of repair or maintenance. In order to ensure product requirements as e.g. corporate identity conformity or even product security guidelines, the customer-manufacturer has to fulfill the requirements/design rules of a temporary member of the value network.

For doing this, the following main functionalities are necessary:

- Functionalities for the foundation and management of collaborative network partners: providing detailed information about each member, and including of new members or removal of members.
- Collaboration spaces functionality allows network members to collaboratively share related information about projects, products, opportunities at one place.
- Product and process portfolio functionality provides a 360 degree view of the products and processes/services offered by network members, including product components, associated services and stakeholders involved. Standardized workflows for AM-processes are defined.
- Product configuration and specification: The product configuration and specification component supports the configuration of customized products based on mass production.

This concept will lead to a complete *change of the "mind-set" concerning how to build up the value chain architecture*:

Without the use of AM: Every process of PLC is realized by the manufacturer and his network – independent from efficiency. Spare parts for example will not be made from a whole piece, due to unavailable tools and be replaced by expensive experts worldwide on-the-spot, anymore (e.g. for special machine manufacturers).

With the use of AM: Service provider or the customer himself can manufacture a spare part on-the-spot by using AM. Interface to the product is suitable designed, all information regarding the required processes, tools etc. are delivered by the manufacturer using the system depicted above.

This concept will create a *loss of value* for the manufacturer due to the loss of the manufacturing of the customized components – but this loss of value might create an increase of profit due to the savings of the complexity efforts created by the customized components.

6. Conclusion and outlook

AM can help to increase the Mass Customization approach in order to create more value to the customer; AM can also enable the manufacturer to shift non-standard or customized processes to the AM service provider – which could be also the customer!

In order to do so, there are changes necessary concerning the

- Product (design) architecture – to enable a product (component) being printed directly by a 3D-printer.
- Value Chain architecture – to enable a service provider or even the customer to become member of the value chain by printing the product component by himself.

Both of these changes will lead to a top-down strategy which – based on the business model – define the value creating setup (c.f. Figure 5). Based on that, design rules have to be created. In case of the value increasing scenario (Figure 5 left hand side), new business capabilities are needed to enable customer co-creation within given BOMs. Further it has to be ensure, that WP2 contain assembly know how which has to be confidential. Those two facts – giving access to a middle part of the BOM and on the same time keeping business knowledge to the working package secure, is a huge challenge.

Regarding the value decreasing scenario on the right hand side seems to be attractive because of the increasing solution space which can be defined by the customer. But as shown in Figure 5, companies who choose this strategy, have to build up capabilities in handling manufacturing networks. Thereby they have to decide which role they want to overtake.

Additionally, both strategies seem to bring challenges regarding the business IT along. In both cases there is a need for

- standardized software architectures for the design process done by the customer that supports also standardized workflows in order to make the whole system applicable to many use cases, and
- standardized software-supported functionalities to manage an agile collaborative network where even customers can be part of in order to build the basis for different business models.

Those new requirements have to be part of future research activities.

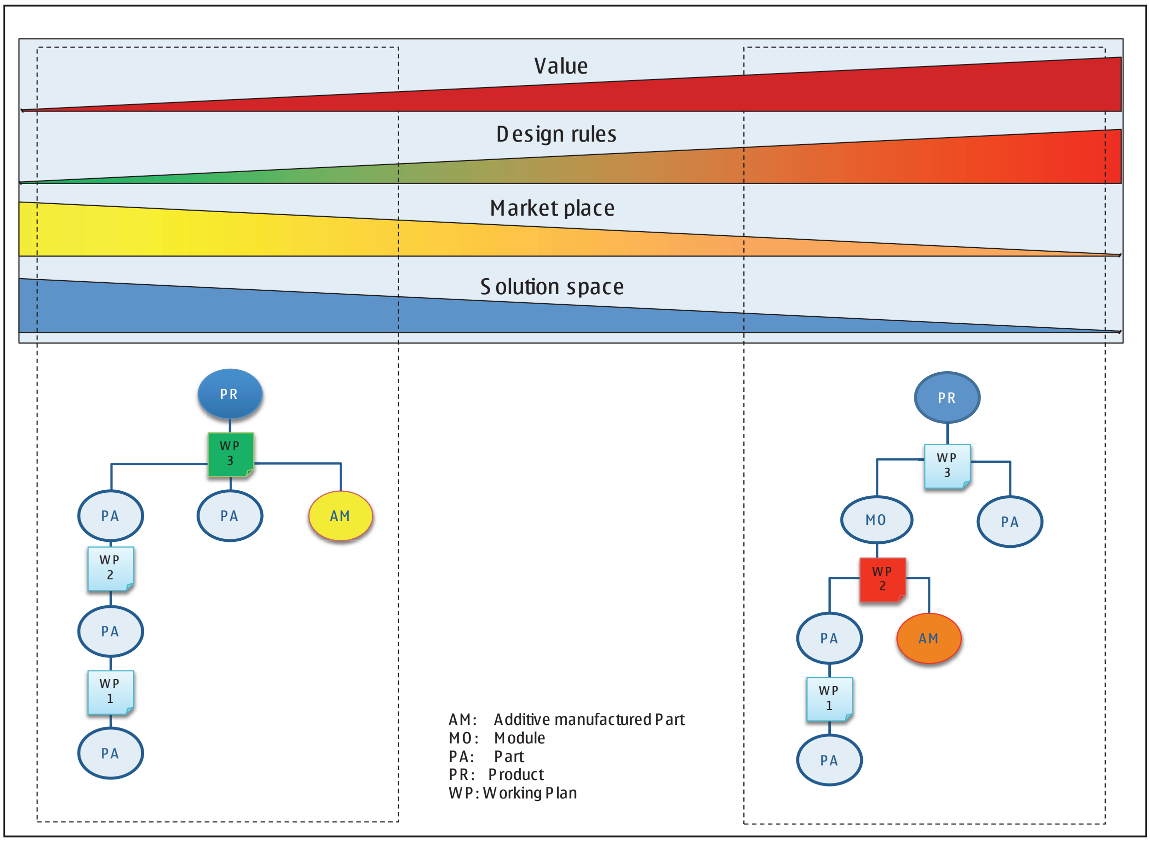

Figure 5: Manufacturing engineering concepts for lifecycle oriented value-increase or value-decrease

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