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The perceived value of additively manufactured digital spare parts in industry: An empirical investigation

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ABSTRACT

The purpose of this paper is to verify the conceptual benefits of the implementation of additive manufacturing (AM) in spare part supply chains from the point of view of industry. Focus group interviews consisting of five sessions and 46 experts in manufacturing were conducted for this study. The focus group interviews served to identify the issues in the adoption of digital spare parts (DSP) and to expand on the available literature. The benefits found in the reviewed literature were partially verified by the participants but certain limitations, such as the excessive need of post processing, supplier quality parity, and ICT inadequacies, were presented that were absent or not highlighted in literature. The information gathered from the participants made it possible to create a realistic model of a digital spare part distribution network. According to the focus group interviews, digital spare parts could be deployed immediately for a specific type of product in the long tails of company spare part catalogues. However, improvements in AM, company ICT infrastructure, and 3D model file formats need to be achieved for a larger deployment of DSP.

1. Introduction

Additive manufacturing (AM) has certain advantages over traditional manufacturing in that it allows for viable lot-one-size production because no tooling and minimal set-up time are needed (Mellor et al., 2014). Therefore, the additional costs of part complexity and variability are significantly lower than in traditional manufacturing and the total delivery time for AM is typically shorter (Simhambhatla and Karunakaran, 2015; Weller et al., 2015). Another major benefit of AM is that, compared to subtractive manufacturing, the expertise needed to operate AM machinery is more easily transferable between product types. (Jonsson and Holmström, 2016).

While AM was originally used to produce prototypes, it is now used increasingly for industrial end-use applications (Kellens et al., 2017). The increase in end-use applications is also observed in the annual AM global report produced by Wohlers Associates, in which they report that, in 2012, 28.1% of all additively manufactured objects were functional parts, while in 2016 the respective percentage was 33.8% (Wohlers, 2013, 2017). In addition to the growth of the relative percentage, the absolute number of produced end-use parts has grown greatly, because the worldwide revenue of AM products and services grew from $2.25 billion in 2012 to $6.05 billion in 2016 (Wohlers, 2017). However, Schniederjans (2017) reported that only 10% of the companies they interviewed use AM to produce end-use parts. Since the percentage given by Wohlers is calculated from the total amount of additively manufactured parts, it follows that although few companies use AM for end-use production, they use it to produce parts in large quantities.

With the fact that end-use components can now be created with AM in mind, several researchers have presented that spare parts could be digitized and additively manufactured. This article aims to validate the results of the researchers by analysing the results of focus groups and to define the concept of AM of spare parts.

1.1. Advantages of additive manufacturing in the supply chain

It has long been hypothesized that implementing AM in supply chains would lead to significant benefits, to the point that AM has been likened to the internet in its ability to cause a paradigm shift (Holmström and Partanen, 2014). Pérès and Noyes were some of the first researchers to suggest implementing AM in supply chains in order to manufacture spare parts closer to the point of need (Pérès and Noyes, 2006). They presented several avenues of research to verify the potential of the concept: research into technical features of spare parts

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(materials, tolerance, life cycle etc.), organisational features (logistics, storage, recycling etc.), and economical features (total cost of spare part). These research questions have been investigated extensively in recent literature (Mellor et al., 2014; Lindemann et al., 2015; Lyly-yrjänäinen et al., 2016; Oettmeier and Hofmann, 2016; Rylands et al., 2016).

Some of the benefits of introducing AM in a supply network include reduced changeover time (Tuck et al., 2007), decreased energy costs (Gebler et al., 2014), and increased sustainability (Kothman and Faber, 2016). Another trend in the research concerning AM in supply chains is exploring what the role of the customer could be in the process. With the emergence of AM, the customer could potentially have control over the design and production of components alone or in collaboration with the company whose product is being redesigned. This type of consumers are referred to in literature as prosumers (Fox and Li, 2012; Rayna and Striukova, 2016; Rylands et al., 2016).

Pérès and Noyes noted in 2006 that AM was too limited to produce end-use components. While there has been significant improvement in the technologies since then, as is implied also by the growth of end-use part manufacturing according to Wohlers associates, there are still severe limitations. For example, the viable maximum part size in AM is smaller than is desirable when manufacturing precise components (Gausemeier et al., 2012), the price of material for AM is higher than in conventional manufacturing (Scott and Harrison, 2015), the cost of AM systems is high (Thomas, 2016), and the material selection in AM is quite limited when taking into account the needs of companies from different sectors (Singh et al., 2017). Additionally, materials must be approved for certain applications, which must be done to every single material (Gray et al., 2017). For the strictest applications, each manufactured material batch requires verification of quality (Portolés et al., 2016). A thorough list of barriers to progression of AM for end-use products as perceived by industry has been collected and published by Thomas-Seale et al. (2018).

Although there are still clear limitations, AM technology has advanced enough to be a viable manufacturing method for end-use components in certain applications (Lindemann et al., 2015). With the notion that components could be moved digitally and produced locally, the question of piracy has been brought up by Lindemann et al. (2015) and Appleyard (2015), who present two opposing views. While Lindemann et al. present that protecting the 3D designs to deter their copying is the right approach Appleyard argues that companies might need to change their approach to spare part distribution to be more open.

1.2. Potential of AM in spare part management

Spare part management is a vital part of many capital-intensive businesses having direct impact on the availability of high-value capital assets, essential to the operational processes (Driessen et al., 2015; Behfard et al., 2018). In fact, unavailability of a spare part item when needed may lead to long unproductive downtimes affecting the operating company's profit (Sarker and Haque, 2000). Given the general function of spare parts to support maintenance activities, the policies that govern the spare parts inventories are different from those that govern other types of inventory such as raw material, work-in-process and finished goods inventories (Kennedy et al., 2002; Molenaers et al., 2012; Roda et al., 2014). Specifically, two of the main critical issues when managing spare parts are the high uncertainty about when a part is required and about the quantity of its requirement that derives from the unpredictability of failures occurrence. These are also the reasons explaining why the level of spare parts inventory kept by companies is usually very high in order to try to avoid risk of unavailability, leading to high inventory holding cost (Ledwoch et al., 2018). Moreover, sourcing of spare parts is often limited to one or a few suppliers, causing constraints for the procurement lead time and the costs; or in the opposite case of multiple sourcing, the related risk of the variations of the quality of supplied materials can incur. Obsolescence may also be a problem; indeed, it is difficult to determine how many units of a spare part item to stock for an obsolescent machine (Kennedy et al., 2002; Roda et al., 2014; Driessen et al., 2015). All these challenges opened the path in the scientific literature to the investigation on spare parts integrated inventory management (Kennedy et al., 2002; Cavalieri et al., 2008) and on spare parts supply chain management (Huiskonen, 2001; Kennedy et al., 2002; Martin et al., 2010; Driessen et al., 2015; Zanjani et al., 2014; Driessen et al., 2015, 2015). Moreover, the relevance of studying the AM technology's impact on these topics is evident because the key challenge in spare part management is to maintain high spare part availability with low cost. AM can be of aid in this issue as producing spare parts by AM can lower inventory stock while maintaining a good level of stock out avoidance (Khajavi et al., 2014). Sasson and Johnson (2016) reported that AM can be beneficial in the production of spare parts belonging to the long tail, which Anderson (2006) describes as the majority part of a company's inventory that consists of items with a low demand. Such spare parts include, for example, products that are in a purely after sales stage of their life cycle such as discontinued consumer products, retired machinery, and antique elevators (Liu et al., 2014).

2. Development of the digital spare parts concept

Several studies have specifically paid attention to the potentialities of AM technology in the context of spare parts supply chain to reduce the size of central and local storages, eliminate the need to locate uncommon spare parts in the distribution network, and diminish the duration and cost of logistics (Walter et al., 2004). The concept of spare part production using AM has been investigated by numerous researchers. The main studies specifically focusing on AM and spare part management along with their key findings and identified obstacles of DSP deployment are collected in Table 1.

The studies on AM in supply chain and the digital spare part (DSP) concept shown in Table 1 present an increased value to practitioners in industries that produce or use spare parts. However, although the findings in the body of research of spare part production by AM are generally positive, in reality very few companies implement digital spare parts in their supply chain operations. There is an evident research gap between why the results of the research are so positive and why it is yet to achieve a notable status in the field of maintenance management.

This study attempts to investigate how industrial practitioners perceive the value of DSP proposed by the researchers and to verify whether the results of the body of research are realistic or attractive to the companies that would benefit from the application of this technology. To reach the research objective, the interest of companies needed to be gauged together with understanding if there are relevant limitations for AM of spare parts diffusion in industry. The research was guided by the following research questions:

RQ1: How do industrial practitioners perceive the value of the DSP concept?

RQ2: What are the main advantages and criticalities of the DSP implementation in the perception of industrial partners?

To this end, focus group interviews were conducted with the representatives of industry to verify if their opinions line up with the implementation of AM in spare part supply chains brought up in the literature in sections 1.1 and 1.2.

Another goal of this study, in addition to answering the research questions, was to refine the concept of DSP. From a methodological point of view, the focal concept was created according to Podaskoff's (Podsakoff et al., 2016) stages for developing good conceptual definitions. According to the first stage of the methodology, potential attributes have to be identified by collecting a representative set of definitions. Therefore, relevant literature was surveyed for what other researchers consider critical to the definition of DSP. The potential attributes of other researchers' works have been collected in Table 2 in