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THE IMPACT OF ADDITIVE MANUFACTURING TECHNOLOGIES ON INDUSTRIAL SPARE PARTS STRATEGIES

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Daniel Beiderbeck (CTM, University of Cambridge)
Dominik Deradjat (CTM, University of Cambridge)
Tim Minshall (CTM, University of Cambridge) *

* Please contact the corresponding author for feedback:
thwm100@cam.ac.uk

UNIVERSITY OF CAMBRIDGE

IfM Centre for Technology Management

THE IMPACT OF ADDITIVE MANUFACTURING TECHNOLOGIES ON INDUSTRIAL SPARE PARTS STRATEGIES

Daniel Beiderbeck, Dominik Deradjat and Tim Minshall

Abstract

The paper aims to investigate potential benefits and the applicability of additive manufacturing (AM) technologies for spare parts management in the automotive industry. Research results contribute to a gap in literature on strategic impact of AM technologies on the automotive after sales business.

Firstly, the paper investigates the general validity of AM in the spare parts industry by utilising a working hypothesis which assumes that AM technologies will have a strategic impact on the automotive aftermarket. Secondly, interacting market participants and their relation to potential applications of AM are explored. The research is exploratory in nature and employs a multi-case research approach.

The analysis identified potential benefits in the automotive aftermarket to transform this business by providing individualised spare parts on demand and on location without a necessity for expensive tooling. However, the research also revealed that neither concepts are technically feasible from today's point of view. Nevertheless, additive technologies entail advantages as outlined in this paper that will affect the automotive aftermarket in the future. The paper summarises five findings that can support research in the area.

Keywords:
Additive Manufacturing – Spare Parts Management – Automotive

1 Introduction

In today's globally connected world customer businesses face a fierce competition - this holds true for a wide range of industries. Specifically manufacturing companies and resellers are confronted with an increasing comparability of their products (Cordman, 1991). As a result, barriers to switching a producer vanish and price wars with diminishing margins occur (Gaiardelli, Saccani, & Songini, 2007). Thus, corporations are forced to develop alternative key differentiators in order to succeed in their respective market (Wise & Baumgartner, 1999). Over long periods of time, enterprises tried to achieve these unique selling propositions by focusing on efficiency and cost effective improvements with respect to primary products (Rommel & Fischer, 2013). However, in recent years a shift towards secondary products, i.e. spare parts, can be observed (Aberdeen Group, 2013) (Cohen, Agrawal, & Agrawal, 2006).

A sector that is particularly characterised by the above-named developments is the automotive industry (Gallagher et al., 2005). Spare parts play a major role for the profitability of OEMs and companies consistently try to optimise their production processes. In this regard, a new technology – namely additive manufacturing (AM) – is said to obtain the potential to disrupt the industry.

Considering current challenges in the automotive aftermarket, AM technologies can theoretically provide significant competitive advantages to companies that manage to leverage the technology's potentials (Rommel & Fischer, 2013). To achieve these objectives, appropriate strategic approaches as well as the above-mentioned willingness to innovate business models proactively are required (Giffi, Gangula, & Illinda, 2014) (Hedges&Company, 2014) (DWN, 2014).

This exploratory research aims at investigating and scrutinising the potential benefits of AM technologies for the spare parts management, thus seeking to answer the present research question:

"How can additive manufacturing technologies

impact spare parts strategies in the automotive industry?"

An answer to this question would contribute to both gaps in literature and knowledge expansion in a managerial sense. Companies may benefit from the derived findings by understanding the difference between theoretical and practical advantages of AM utilisation for after sales purposes and might also be encouraged to elaborate further on the technology's potentials.

2 Literature Review

2.1 Additive Manufacturing

Several scholars illustrated, that AM has the potential to support all stages throughout a production value chain (Hague et al., 2003)(Scott et al., 2012)(Berman, 2012) (Atzeni & Salmi, 2012)(Garrett, 2014). Owing to the manifoldness of different systems, AM processes can meet a variety of demands, as illustrated in figure 2-1.

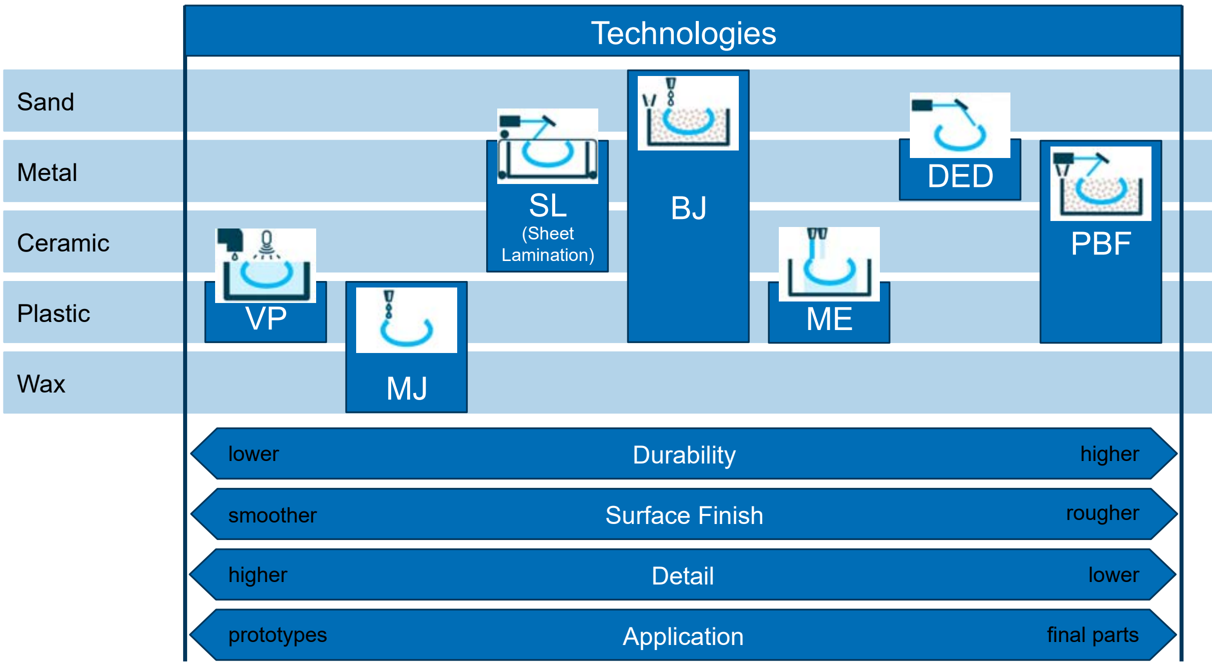

Figure 2-1: AM technologies and their respective characteristics

In principle, additive technologies are able to produce almost every part that can be produced by means of traditional procedures. To what extend this is (or will become) economically reasonable for series production remains doubtful. Yet, benefits of AM utilisation go far beyond the mere fabrication itself. The technology allows companies to be more flexible in their production strategy, which might have a significant influence on spare parts management. This business is of particular importance to manufacturing companies as it holds out the prospect of high margins, but simultaneously it burdens corporate results through the necessity of stockpiling. Considering the increasing variety of items and shorter product introduction cycles, an effective spare parts strategy becomes more decisive than ever.

Therefore, the present article focuses on the application of AM technologies in manufacturing environments and in this connection particularly on the potential impact on spare parts strategies.

2.2 Definition of Spare Parts

General categorisation

With respect to the categorisation, which was used to distinguish parts by objective means, the present research will particularly elaborate on those parts that are considered to be consumables. Hence, repairable and small parts are not subjects of investigation because these parts are unlikely to be manufactured additively.[1] Another objective criterion was addressing the intended use of a spare part. In relation, the main focus of this article lies on control situation 3, thus parts that are meant to repair customer products.

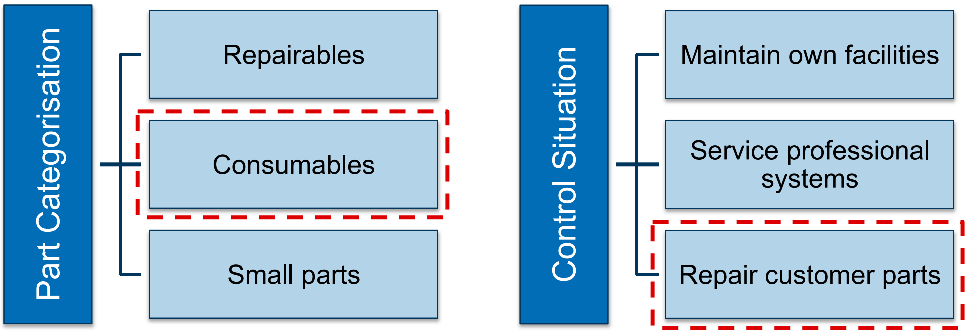

Figure 2-2: Explicitly considered Spare Parts Categories

Spare Parts in the Automotive Industry

Today's spare parts management faces an increasing complexity (Vaisakh et al., 2013) (Saccani et al., 2006). This holds particularly true for the automotive industry, which has to deal with high volume production and an extensive variant diversity. The growing quantity of versions leads to massive warehousing and vast inventory of spare parts (Rommel & Fischer, 2013) (Langlois & Robertson, 1989). Moreover, intricate logistical efforts are needed, because products have to be distributed and transported over long distances with high requirements in terms of delivery and date reliability. Despite these considerable challenges, the so-called 'aftermarket' is a very profitable and thus contested business, as mentioned in the introduction. Therefore, a thorough understanding of this critical branch is of major importance for the further course of this paper.

[1] Note that there is a trend to repair certain parts by utilising AM technologies; however, this does not apply to the automotive industry.

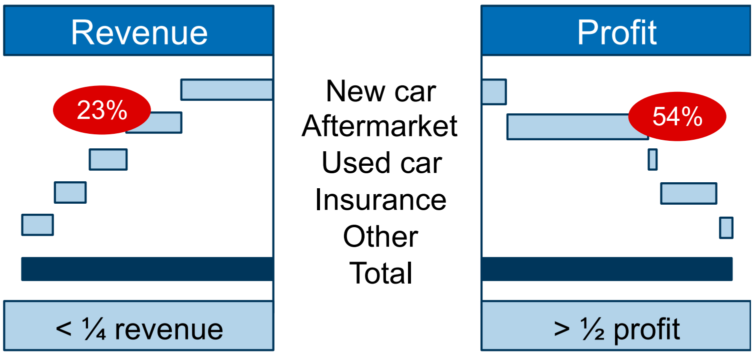

Figure 2-3: Revenue and Profit in the Automotive Industry[2]

Generally, the aftermarket includes activities associated with both products (e.g. spare parts) and services subsequent to an initial sale of a new car (Subramoniam, Huisingh, & Chinnam, 2009). Although the article at hand predominantly focuses on the first aspect of the market, the service offering cannot be neglected since improvements in spare parts provision automatically affect service quality. Literature distinguishes four groups, generating revenue in the aftermarket (Gissler, 2015):

i) OEMs,
ii) Independent Service Providers,
iii) Service Chains, and the
iv) Do-it-yourself-segment.

Definitely, OEMs and their affiliated original equipment services (OES) along with independent manufacturers and suppliers sell the majority of spare parts. In the light of the present research topic, however, it is equally important to understand where these parts come from and therefore figure 2-3 illustrates the distribution network from production to retail in the automotive sector (Diez, 2013). Evidently, supplying companies also play a vital role with respect to the spare parts value chain, which has to be taken into consideration for the remainder of this article.

[2] Based on GISSLER & MÜLLER, 2008, p.2.

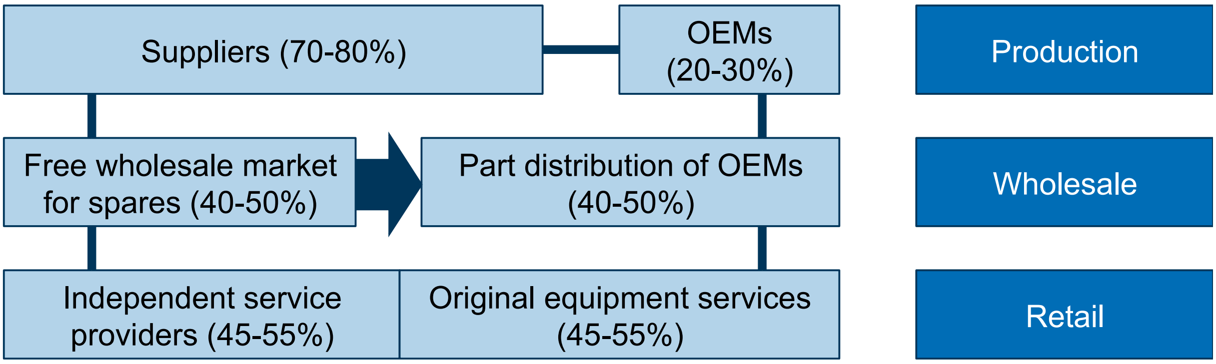

Figure 2-4: Distribution Channels in the Automotive Aftermarket[3]

2.3 AM for Spare Part Production

A number of scholars pointed out that the adoption of AM technologies within the spare parts business is compelling in theory (Tuck & Hague, 2006) (Hasan & Rennie, 2008) (Holmström et al., 2010) (Huang et al., 2012) (Reeves & Mendis, 2015). There are studies that investigate the utilisation of AM to produce final parts (Khajavi et al., 2014).

Spare Parts

Therefore, scholars such as LINDEMANN ET AL. (2012) compare traditional fabrication and additive technologies by means of lifecycle costs, while others exclusively pay attention to production costs (Hopkinson & Dickens, 2003) (Ruffo, Tuck, & Hague, 2006).[4] However, ROMMEL ET AL. (2011) emphasise that the expectations have to shift from "*getting exactly the same product and its material characteristics with another technology*" to "*getting the same performance and functionality of the product regardless of the manufacturing technology*".

Despite this published conception, the majority of research still focuses on the replication of existing parts. It is plausible that - across industries - not every component is worth to be considered an additively manufacturable spare part (AMSP). Figure 2-6 illustrates the two prevailing selection arguments, namely technical infeasibility and economic inefficiency (Gebhardt, 2011).

As a matter of course, the significance of either technical or monetary constraints varies, as indicated by the red arrow in figure 2-6, but the overall result stays the same. Regardless of the particular manufacturing industry, only a small portion of

[3] Based on DIEZ, 2013, p.4.
[4] Since quantitative results are not the main issue of this research, these approaches are not being discussed in greater detail.

parts is suited for additive production (Baldinger, 2014) (Reeves & Mendis, 2015). WALTER ET AL. (2004) argue that from a cost perspective especially slow moving B- and C- parts come into question, which will be tested in the analysis chapters of this article.

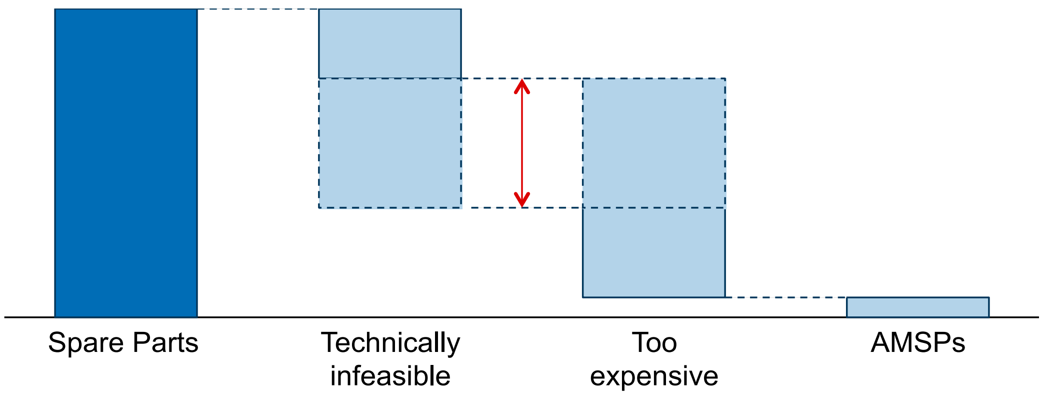

Figure 2-5: Selection of Additively Manufactured Spare Parts

Again, this statement particularly applies to parts that are simply supposed to be replicated. However, as shown in the review of literature on AM, the new technology has the potential to create innovative designs that are not producible by means of conventional techniques (Baldinger, 2014). On the one hand, this is important to the process of series production as a whole because new products can be initially designed for AM, but on the other hand, it could also affect the provision of current spare parts (Gausemeier, 2011).

Value Chain

Essentially, all imaginable supply chain transformations that are described in literature trace back to three pivotal assumptions. Next to the (1) omission of tooling, (2) production *on demand*, and (3) production *on location* are the most salient benefits of AM utilisation (Walter et al., 2004) (S. Hasan & Rennie, 2008) (Khajavi et al., 2014). At this point, all three benefits are deliberately marked as assumption because it remains to be clarified in the course of the paper if these advantages indeed have unlimited validity.

Since tooling issues have been discussed above, the subsequent paragraphs focus on the two latter points. In the past, spare parts provision *on demand* sounded like a utopian dream of inventory managers. However, AM technologies might have the potential to let this wish come true. Several scholars describe how CAD-data of parts can be stored electronically, so that components can be 'printed' instantly and *on demand* (Levy et al., 2003) (Tuck, Hague, & Burns, 2007) (Breuninger et al., 2014) (Reeves & Mendis, 2015). Evidently, this vision is only imaginable without the necessity for tooling and setup, thus point (2) and (1) are inseparably linked (Walter et al., 2004).

One step further than production *on demand* – which would have a dramatic impact on stockpiles at centralised distribution centres – goes the idea of spare part production *on location* (Ponfoort, 2014). This means that parts would not have to be shipped anymore, instead, manufacturers or service providers[5] could produce components near the place they are needed (Rommel et al., 2011). In theory, all it takes is an electronic CAD data transmission and an AM production system on-site. Evidently, this model raises concerns with regard to intellectual property (IP) as well as copyright protection, which is currently being discussed in literature (Santoso, Horne, & Wicker, 2014) (Hornick, 2014) (Garrett, 2014) (Holmström et al., 2010). However, given the limited time of this research project, IP issues and data security are not within the scope of this article.

Conclusively, the possibilities to produce spare parts *on demand* and *on location* represent the most significant arguments for the deployment of AM technologies for after sales purposes in literature. ROMMEL ET AL. (2013) summarised the implied benefits as shown in the table below.

Table 2-1: Benefits of Additive Spare Part Production[6]

Spare part production **on demand**	Spare part production **on location**
no more warehousing for spare parts, including space, building maintenance, energy for climate control, workers, etc.	worldwide service without limitations
no more logistics of scrapping unused old spare parts	no more logistics for end products
no more time limitations for spare parts support	faster response time over long distances

If and to what extend these promises hold true in practice is debatable. The validity certainly depends on the particular industry that is observed. Some scholars tested the benefits in practice, as described in the next sub-chapter. The article at hand inter

[5] Service providers are companies that specialise on the actual 'printing process' (Ford, 2014). Customers send CAD files to service bureaus and obtain the generated parts. This business model will be explained briefly in the next section.

[6] Based on ROMMEL ET AL., 2013, p.120.

alia aims at investigating the veracity of assumptions made in literature for the automotive industry.

2.4 AM for Automotive Spare Parts

The previous chapter illustrated that the carmakers have profound experience with AM for prototyping purposes, which means that technology expertise is already existing within these companies; at least to a certain degree. Moreover, it was shown that not only OEMs, but also newcomers, try to adopt additive techniques for the production of final parts, or even entire cars. Thus, considering the earlier presented benefits of AM technologies for spare parts, the automotive industry offers excellent conditions, which is why the present section reviews existing literature on AM utilisation for spare parts management in the passenger car sector.

The view on the automotive industry will be subdivided into three steps. First, spare parts themselves are examined in isolation. Then, literature on the evolution of supply chains will be reviewed, before holistic business model ideas will be presented in a third and last stage (see figure 2-9).

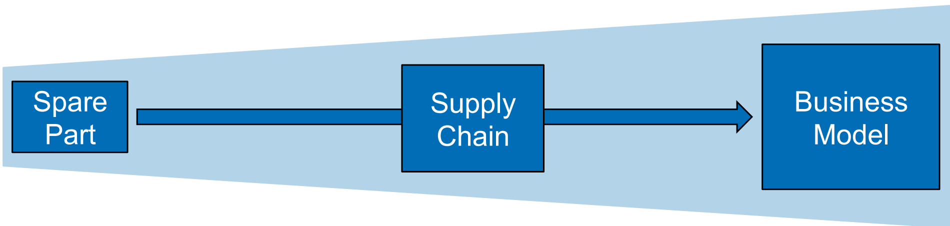

Figure 2-6: Structure of Literature Review for the Automotive Industry

As far as spare parts are concerned, Reeves and Mendis (2015) just recently published a study on “3D printed parts in the automotive aftermarket”. They underpin the compelling potential of AM technologies for the spare parts business, picking up the advantages of both on demand and on location production. However, as one of the first scholars they did not only point out theoretical benefits but also analysed definite advantages, taking the current technology status into account. In this regard, they found out that despite the huge overall market size, only a small fraction of the parts is indeed worth to be considered for additive production.[7]

The scholars pointed out that tyres, brake pads, and batteries alone represent more than 50% of all expenditure (Reeves & Mendis, 2015). In fact, it is not possible to produce these parts by means of additive techniques and this holds true for a wide

[7] Reeves and Mendis (2015) estimated the automotive aftermarket at £130 billion in total.

range of other components as well. Still, table 2-6 illustrates a list of items that come into question when thinking about AM.

Table 2-2: Common Automotive Spare Parts[8]

Component	Technically feasible	Economically viable	Percentage expenditure
Radiators	Yes	No	3.1%
Water Pumps	Yes	No	2.9%
Exhaust Pipes	Yes	No	0.8%
Silencer Boxes	Yes	No	0.8%
CVJoints	Yes	Possibly	0.7%
Wheel Bearings	Yes	No	0.5%
Rack and Pinion	Yes	Possibly	0.2%
Distributor Caps	Yes	Yes	0.1%
Brake Callipers	Yes	No	10.4%
Brake Disks	Possible	Possibly	2.4%
Shock Absorbers	Possible	Possibly	2.2%
Fuel Pumps	Possible	Possibly	2.1%
Catalytic Converters	Possible	Possibly	1.3%

REEVES AND MENDIS (2015) illustrate that only a small portion of spare parts is interesting for additive production and that most of these components are too expensive to 'print'. In sum, the scholars present a rather pessimistic outlook and do not expect AM technologies to affect the automotive aftermarket within the next 15 years.

GIFFI, GANGULA, AND ILLINDA (2014) take a more optimistic position and point out the advantages of AM technologies for 'long-tail components' – meaning parts with sporadic demand in small volumes.[9] To this effect spare parts for classic cars are an often-mentioned example (Gebler et al., 2014) (Fawcett & Waller, 2014). GAUSEMEIER (2011) also emphasised the importance of this segment, because of current trends in the automotive industry. While product life times decrease in almost all manufacturing sectors, this does not hold true for the aftermarket. On the contrary, the expected durability of a passenger vehicle increases (DWN, 2014). Concurrently, OEMs bring new models to market more rapidly, thus, increasing the variety of spare parts in circulation (Gausemeier, 2011). Obviously, the diversity of required parts forces OEMs

[8] Based on REEVES AND MENDIS, 2015, p.17.
[9] In this connection they see aftermarket part suppliers affected by the technological change rather than the OEMs, which is an opposed opinion compared with REEVES AND MENDIS (2015).

and suppliers to hold more different items on stock for a longer period of time. Hence, the benefits of fabricating parts on demand would be even more powerful.

Assuming production on demand would be feasible, TUCK ET AL. (2007) examined the impact of AM on the automotive supply chain.[10] Pivotal advantages of additive technologies were detected. With respect to spare parts, one aspect stood out, namely the 'dematerialisation of supply chains' (Tuck et al., 2007). While this also plays a vital role for the actual production process, the present focus will be on spare parts provision. The scholars point out that reduced stock levels will impinge positively on profitability and that the opportunity to produce on location will lower logistic costs. Parts will be stored 'virtually' and produced when they are needed. In this connection BEYER (2014) presented a real-life example of General Motors. The company has implemented an 'automatic stock-replenishing programme' which is meant to free dealers from inventory risks by allowing them to return parts that do not sell within 15 months. Still, the dealers have to store all components for more than a year, and from a company's point of view unused parts often have to be scrapped (Rehme, 2011). BEYER (2014) also named production on location and on demand as the best way to overcome these obstacles. However, the degree to which these visions are indeed realistic for the automotive industry remains questionable.

Nevertheless, potential benefits in terms of eliminated waste, less warehousing, and limited transportation are salient, and induced the European Union to fund a collaborative research project called 'DirectSpare'. A consortium of professionals from different industries (particularly interesting for this article is *BMW*), technology specialists (e.g. *EOS* and *Materialise*), and further experts (e.g. for legal issues) tried to develop a business model that incorporates the various advantages of AM technologies for spare parts provision (DirectSpare, 2013). Figure 2-10 shows a simplified structure of the proposed commercial model.

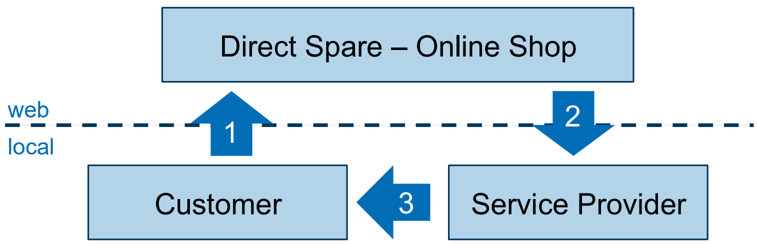

Figure 2-7: DirectSpare Business Model[11]

[10] In particular they investigated the impact on both the lean and agile supply chain paradigms (Cox, 1999) (Naylor, Naim, & Berry, 1999). Considering the limited scope, these are not being discussed in greater detail in this paper.
[11] Based on REHME, 2011, p.2.

The central idea was to establish an online platform that connects customers and service providers in an efficient manner. Although a detailed analysis of the three-year research project would go beyond the scope of this article, two things are worth considering.

First, the proposed business model was not eventually put into practice by any of the consortium members. However, it is notable that other companies established very similar service offerings (Reeves & Mendis, 2015). At this point, the already mentioned websites *Thingiverse* and *Kazzata* are to be named representatively. In fact, *Thingiverse* offers a series of spare parts for classic cars – for example 'cold air intakes' for a Porsche 948.[12]

Second, the case study of *BMW* is of particular interest, because it was the only participating carmaker. Specifically, *BMW* examined two components, namely a front grill for an antique car where tools were obsolete, and a head light cover which ran out of stock and could not be produced anymore, also because of missing tools (Rehme, 2011). Although it was possible to re-engineer and 'print' both parts – the former from aluminium, the latter from plastic (PP Copolymer) – the parts were not fit-for-purpose (DirectSpare, 2013) (Reeves & Mendis, 2015). Thus, from a 2009 perspective, when the study was conducted, *BMW* concluded that AM technologies were not yet deployable for spare parts production. In how far this still holds true today will be examined in chapter four.

[12] See: http://www.teil-der-maschine.de/?p=3252. Note that many other parts are also available and that this component is mentioned as a representative example.

In order to understand the impact of AM technologies on spare parts management, chapter 2 reviewed literature on current technology applications. The structure revealed, that additive fabrication has the potential to affect not only the characteristics of parts themselves but might also transform value chains and eventually let new business models emerge. Figure 2-11 summarises these impacts visually.

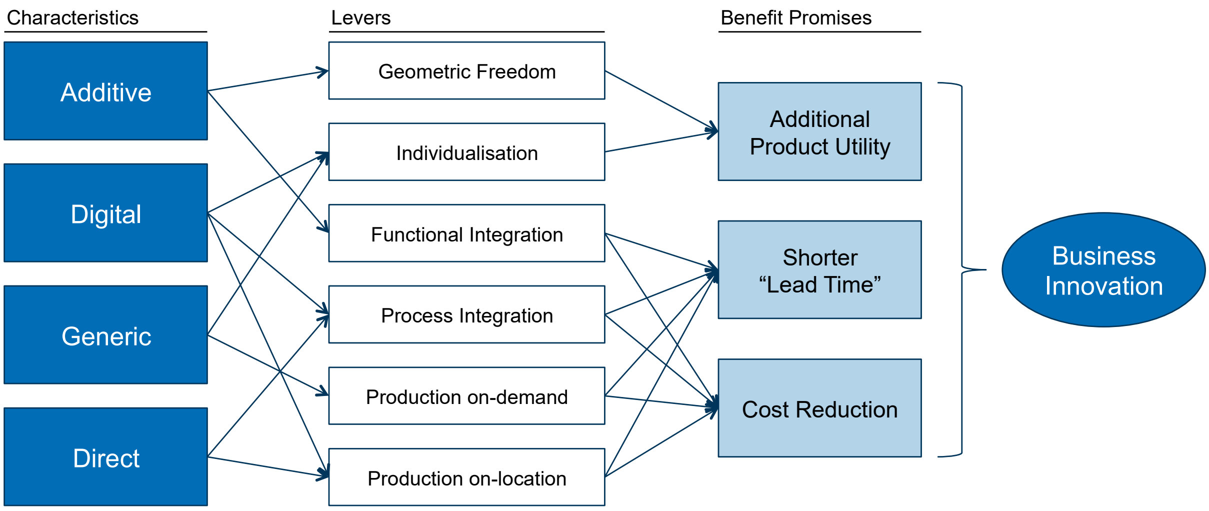

Figure 2-8: Value Proposition of AM Technologies[13]

Considering the potential supply chain transformations, it was found out that three major expectations were always underlying, namely production (1) without tooling, (2) on demand, and (3) on location.

However, most publications pointed out theoretical advantages of AM processes, accepting the above-listed assumptions as valid. Only a few scholars tested the potential empirically and those who did, particularly focused on the aerospace applications, which is why this sector was presented explicitly as an industry example.

The goal of the present research is to identify the strategic impact of additive technologies on the automotive aftermarket. Therefore chapter 2.4 specifically focused on the interface between AM and spare parts management in the car making industry. A series of scholars proposed various potential scenarios of how the technology might affect after sales services, however, only REEVES AND MENDIS (2015) tested the impact empirically. Yet, they particularly examined OEMs, thus focusing on operational and tactical effects. It was pointed out that despite a new design freedom arising from AM technologies, the inherent limitations in the process are still keeping AM processes from being a panacea for the majority of fabrication problems (Garrett, 2014). Not only technical feasibility but also economic reasonability has to be secured, which currently limits the technology's application to low-volume production.

[13] Based on SCHOLZ-REITER, 2013, p.13.

Nevertheless, the theoretical advantages of AM for spare parts provision are compelling, so that an empirical investigation of strategic impacts of AM technologies for the automotive aftermarket would contribute both to theory and practice. In contrast to REEVES AND MENDIS (2015) the perspective will be more strategic, considering not only OEMs but also supplying companies and technology experts, in order to generate a comprehensive understanding of how AM technologies might affect industrial spare parts strategies and probably transform the industry structure.

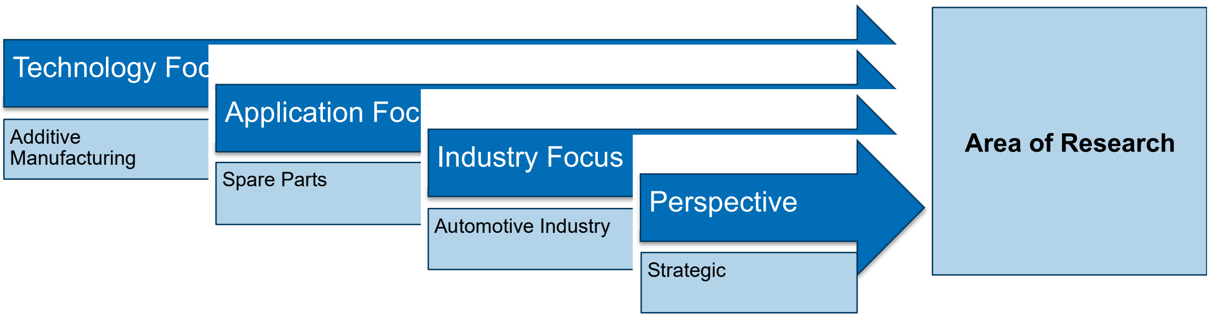

Figure 2-9: Area of Research

Figure 2-12 illustrates the detected gap in literature and hence the present area of research visually. The following chapter is going to elucidate both the research structure and the applied methodology in detail.

3 Research Methodology

As argued above, the present research follows a qualitative approach, using case studies as the most suitable research method. Therefore, this section comprises the design and selection of the cases as well as the data collection and analysis process.

Case Study Design

Regarding the case study approach, YIN (2013) itemises four research design categories, as illustrated in figure 3-1.

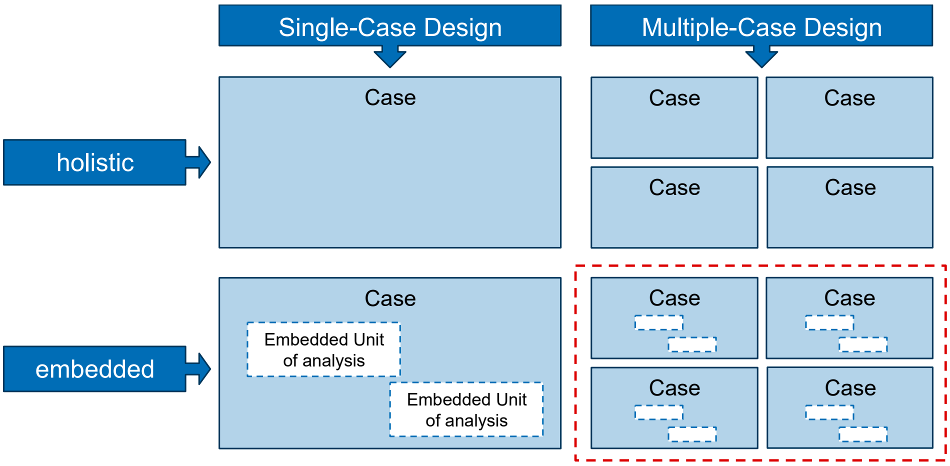

Figure 3-1: Four Categories of Case Study Design[14]

The first distinctive feature refers to the quantity of cases, whereby single-case and multiple-case designs are differentiated. Above that, a second dimensions distinguishes holistic and embedded methodologies, resulting in:

i) single-case (holistic) approaches,
ii) single-case (embedded) designs,
iii) multiple-case (holistic) research, and
iv) multiple-case (embedded) methods.

For the present article, the latter approach was chosen for the following reasons: First, a multiple-case concept enhances the reliability of the findings, especially with regard to the hypotheses testing in chapter four. Second, it minimises the observer-bias and therefore ensures broader significance for the automotive industry (Voss, Tsikriktsis, & Frohlich, 2002). Finally, the embedded approach appears suitable, because not only opinions on existing theories of how AM technologies might affect

[14] Based on YIN, 2013, p. 47.

spare parts management are supposed to be tested, but also individual views on potential future developments.

Case Selection

Evidently, a strategic choice of cases can facilitate the generalisability of derived results (Flyvbjerg, 2006). Therefore, a defined selection process is important, which is to be disclosed in this section (Eisenhardt, 1989).

With respect to the automotive aftermarket it was pointed out in the literature review that not only OEMs, but also supplying companies are in charge of spare part provision. Moreover, the research aims to examine the impact of AM technologies for the entire industry, which is why company-independent expectations might also reveal crucial insights. Hence, relevant categories of cases include four groups:

i) Automotive OEMs:
   - Employees involved with either additive manufacturing technologies, or spare parts management within the corporation

ii) Suppliers:
   - Exclusively companies fabricating spare parts, either for OEMs or for the independent aftermarket

iii) Industry experts:
   - Either specialised consultants or scientists

iv) Technology experts
   - Either specialised consultants or scientists

Each of these groups is ideally represented by more than one case in order to yield dependable results.

Data Collection and Analysis

According to the selection process elucidated above, empirical data was collected by means of semi-structured interviews. In total, 23 interviews were conducted with interlocutors from the companies listed in figure 3-2. With respect to the limited amount of time during a five months article, contact persons at each company or institution were interviewed once.[15]

[15] Note: Quotes from interview partners are personal opinions and explicitly do not represent official corporate standpoints. They are to be considered as subjective expert knowledge.

OEMs & Suppliers	Industry & Technology Experts
BMW	Accenture
Jaguar Land Rover	Roland Berger Strategy Consultants
Daimler Benz	Barkawi Management Consultants
Volkswagen	German Association of the Automotive Industry
Audi	Direct Manufacturing Research Centre
Ford	Chair Manufacturing and Remanufacturing Technology
Meyer Fine Blanking Company	Fraunhofer IPA
Croft Additive Manufacturing	3D Systems
Hella	Materialise

Figure 3-2: List of conducted Case Studies

For the purpose of unbiased ex-post analysis, interviews were recorded or written in shorthand (Voss et al., 2002). Relevant statements were transcribed as empirical data and will be quoted in the remainder of this article either in body text or footnotes. Further context information was gathered by means of a thorough literature review and the consideration of secondary data.

This chapter clarified the applied research methodology in detail. Pivotal research objectives were pointed out, whereupon ontological and epistemological considerations were argued. A rather interpretivistic stance emerged as an appropriate philosophical positioning. With regard to the theory development process, it was shown that the present article covers an entire loop within the cycle of theory testing and constructions; starting off with a deductive approach in chapter 4.1 before generating a new theory in a bottom-up, inductive manner in chapter 4.2. For this purpose, the embedded multiple-case method proved to be an appropriate research design. Statistical testing and validation is explicitly outside the scope of this work.

4 Results and discussion

4.1 Initialisation Stage

As mentioned earlier, an increasing utilisation of AM in early stages of the value chain of automotive enterprises has already initiated a change process concerning the after sales business. On this account, a strategic view on the status quo of AM for spare parts purposes is advisable. Therefore, the chapter at hand deals with the working hypothesis that was developed as a conceptual framework for this part of the paper.

"*AM technologies will have a strategic impact on the automotive aftermarket*".

CHESBROUGH & ROSENBLOOM (2002) emphasise that strategy has to focus on capturing value for a venture itself with an evaluation of competitive threats from other actors within a market. With respect to spare parts, competition is certainly relentless and, considering the growing importance of this business, a thorough understanding of influencing factors is all the more significant (Boylan & Syntetos, 2007). In order to provide this comprehension, the present section is structured along the following sub-hypotheses:

i) AM technologies theoretically have the potential to transform the automotive aftermarket,
ii) AM technologies allow carmakers to produce on demand,
iii) AM technologies allow carmakers to produce on location, and
iv) AM technologies are competitive compared with conventional processes.

Each sub-hypothesis will be tested in a separate section before the superordinate working hypothesis will be discussed at the end of this chapter.

Disruption in the Spare Parts Market

Scientific literature offers a variety of models helping to analyse a particular market and its environmental influences. In this connection the 'PEST-Analysis' and the 'Five-Forces-Model' are being applied in order to underpin the disruptive characteristics of AM, not only regarding the manufacturing process itself but also relating to business strategies (Glaister & Falshaw, 1999) (Porter, 1979). Since this section primarily focuses on theoretical impacts of AM on the spare parts market, references to the conducted case studies will be scarce.

Production on Location and on Demand

While the previous section predominantly aimed at illustrating potential benefits of AM technologies for spare parts provision, this paragraph tries to test if the pivotal assumptions made in literature also hold true in practice. Several scholars proclaimed that AM technologies enable manufacturing companies to produce parts on demand and on location (Walter et al., 2004) (Rommel & Fischer, 2013) (Giffi et al., 2014) (Gibson et al., 2015). The underlying reason for this is the fact that the actual generation process does not require any tools. Therefore, tool-making processes can be eliminated, and thereby expensive, time-consuming retrofitting of machines is no longer necessary – at least in theory (Hague, 2006) (Scott et al., 2012). This leads to a visionary scenario in which car dealers operate with AM systems on location, printing spare parts for customers whenever they need them (Giffi et al., 2014).

Pivotal advantages of the above-described setting were often emphasised in literature (see chapter two), but drawbacks were often neglected. Thus, in order to check on the veracity of this idea, interviews with technology experts were conducted. The specialists who were consulted work for automotive OEMs and AM system manufacturers, or suppliers are leading scholars in the field of rapid manufacturing. For the purpose of understanding to what extend decentralised production by request is realistic, the respondents are not being distinguished according to their employers.

Comparing production on location and on demand it turned out that experts attach less importance to the former aspect for different reasons, which are being described below.

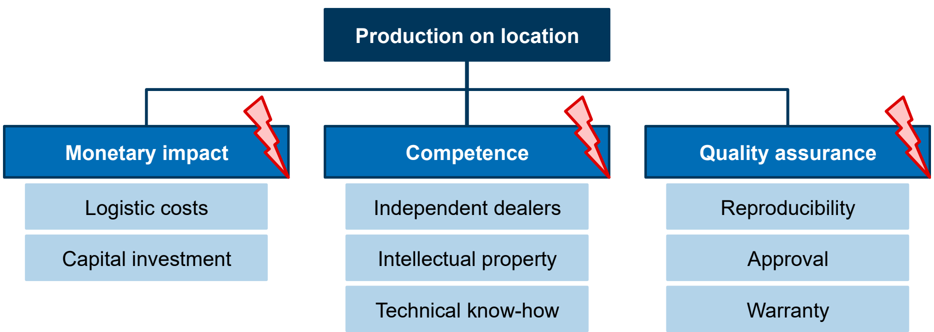

Figure 4-1: Barriers to Production on Location

Production on location by means of AM facilities faces barriers in three dimensions, namely: (1) monetary impact, (2) competence, and (3) quality assurance.

The first drawback of producing spare parts on location is the low monetary impact for OEMs and suppliers. Experts pointed out that *logistic costs* for automotive spares play a minor role.[16, 17] Thus, considering the *capital investment* required to install a basis of AM systems at dealerships across a country, it seems unlikely that every workshop will be equipped with an own AM machine within the next decade.

At this point, the second aspect, competence, is relevant in three ways. On the one hand, it is questionable who would be responsible for the purchase costs of AM machines, since most dealerships operate as *independent entities*.[18] Against this backdrop, it is difficult for OEMs to force authorised dealers to buy AM systems. However, providing workshops with machines paid by the headquarters would cause immense costs.[19] On the other hand*, intellectual property* (IP) concerns are often mentioned in literature. The theoretical advantage of simply sending CAD-data digitally to the dealerships that print spare parts on location entails risks concerning data security.[20] Although REEVES AND MENDIS (2015) pointed out that IP might not be a central issue because dealers would not jeopardise their licenses by abusing any data, information could be stolen from third parties. This certainly is a danger, because the data has to be transmitted to the workshops, which is always critical since IT-systems at dealerships are not as secure as those in the headquarters.[21]

Moreover, competence can be understood in terms of *technical know-how* rather than responsibility and this facet also displays a problem. Dealerships certainly will not employ AM experts in order to operate the systems. Therefore, it would not only be necessary to send the CAD-data of spare parts digitally, but also machine settings and other information that enable workshop employees to operate the AM facilities. According to technology experts this problem is severe and it underpins the already-

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[16] "[…] our logistics network is so efficient that transportation costs hardly play a role" (Bellamy, 2015).
[17] "Compared to inventory costs, the logistics expenses of spare parts are negligible" (Rommel, 2015).
[18] "Carmakers have an impact on their dealers, but in the end OEMs cannot oblige authorised workshops to pay for AM machines out of their own pockets" (Gissler, 2015).
[19] "OEMs are stock companies that have to justify investments to their stakeholders. […] Installing AM machines at workshops across a country would be a multi-billion euro project. Given the high degree of uncertainty, it is hard to convince stakeholders of such an investment." (Gissler, 2015).
[20] The file type that is required for AM machines is STL. However, it is easy to convert this format from CAD-files, so that for the purpose of an easy understanding it is assumed that CAD is the format in which data is being transferred.
[21] "Data security is an issue. Actually AM has a natural counterfeit protection, because it is not sufficient to have the 3D model alone. In order to produce a part with certain mechanical properties, you need to know the correct machine settings […]. If companies transfer all these information to workshops with mediocrely secured internet connections, this might be a problem" (Klemp, 2014).

mentioned importance of highly secure data transfer.[22] Above that, missing skills in using AM systems might affect the outcome of generated parts, which leads to the third and probably most aggravated problem when thinking about production on location and this is quality assurance.

Quality assurance is a major issue for automotive OEMs and thus also for suppliers of spare parts.[23] Original parts have the highest standards and the manufacturer of each item has to guarantee that all units of this item have the same quality. Thus, imagining a scenario in which workshops print spare parts on location, this requirement leads to three decisive challenges.

First, *reproducibility* of parts has to be assured. Concerning conventional manufacturing technologies like injection moulding, deep drawing, or fine blanking, for instance, each batch is being monitored by random checks.[24] These processes are designed for large-scale production with recurring quality. Current state of the art AM systems, however, still have problems to generate parts with exactly the same properties both in terms of shape and mechanical characteristics.[25] This holds true in general and is neither an industry-specific problem nor related to production on location in particular. Yet it leads to drawbacks that are relevant for the automotive spare parts production.

Regarding the former aspect, additively manufactured (spare) parts can be produced near net shape as illustrated in the literature review. But it was also emphasised that the majority of generated components still needs post-processing, which entails the problem that suitable milling machines, or even furnaces would have to be installed at each workshop.[26, 27] This appears unlikely considering the necessary capital investment. However, without these facilities, the mechanical characteristics of produced parts could not be reached. This holds particularly true for metal parts that might be classified as vital or essential.[28]

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22 See footnote 81.
23 “Consistent quality has top priority. […] With regard to AM technologies, process reliability is still a problematic issue” (Caspar, 2015).
24 “We are obliged to control and record the quality of each batch that we produce. […] This is not only true for our stamping parts but also those parts that are produced in smaller quantities” (Meyer, 2014).
25 “In connection with AM people always talk about ‘lot size one’, however, this is almost impossible in our industry, at least when it comes to functional parts. […] Mechanical properties have to be tested and we often need destructive inspections to do this. However, if you cannot assure that printed parts are identical in terms of geometry, structure, etc. these tests have no significance” (Caspar, 2015).
26 “Metal parts need post-processing, e.g. stress relief heat treatment” (Felsch, 2014).
27 Note that this is only true if AM systems would be installed at all dealerships or workshops. Evidently, this is a utopian scenario, however, as described in chapter three, working hypotheses are meant to test extremes in order to yield findings that answer an overarching research question.
28 “We are predominantly investigating non-visible plastic components” (Finsterwalder, 2015).

Especially when it comes to these functional parts, a second problem arises when visioning a production on location scenario – the *approval*. Even if it would be possible to equip a series of dealerships with the required machines, the approval process would be very complex. Industry experts point out that "a centralised approval for a part that is produced additively at different locations would presuppose that all machines operate at exactly the same conditions. Not only environmental conditions such as temperature and air humidity would have to be controlled, but also the flow of material would have to be reproducible. […] Assessing thousands of dealerships and their individual AM facilities would result in tremendous costs" (Caspar, 2015). Evidently, this process of approving decentralised and additively manufactured parts implies obstacles that can hardly be overcome from today's point of view. Without such an approval, parts that are printed on location will not be sold under *warranty* and from an OEM's perspective this means that these parts will not be sold at all, which currently impedes the vision of spare parts production on location.[29]

In summary, both industry and technology experts do not see medium-term potentials for a production on location scenario, at least when thinking about AM systems that are installed at the workshop or dealership around the corner. However, on a larger scale, understanding production on location as producing spare parts regionally in each country – and not in each city within a country – the concept appears more realistic and might become relevant in the future.[30] In one interview industry representatives mentioned rising issues concerning taxes and customs duties when shipping spare parts to foreign countries (Company A, 2015). Establishing a distribution centre in each country, employing local staff and producing spare parts additively within the borders of the country to be supplied, might be a visionary solution to solve this problem.[31] However, given the limited scope of the present paper, this aspect will not be elucidated any further.

As indicated in the previous section, experts attach greater importance to the opportunity of producing spare parts on demand. Therefore, this paragraph deals with both the benefits and current barriers to additive fabrication by request.

[29] "Our quality standards are very high and even if the additively manufactured parts would meet the requirements, the process itself would still have to be approved. As long as this unsuccessful, printed parts will not be sold" (Caspar, 2015).
[30] "Since we operate with smaller volumes within the market for utility vehicles, it would not make sense to have multiple dealerships with AM facilities within one country. However, since we serve customers worldwide, local production plants could be a practical scenario" (Company A, 2015).
[31] "Some governments subsidise foreign manufacturers that build production plants in their country" (Company A, 2015).

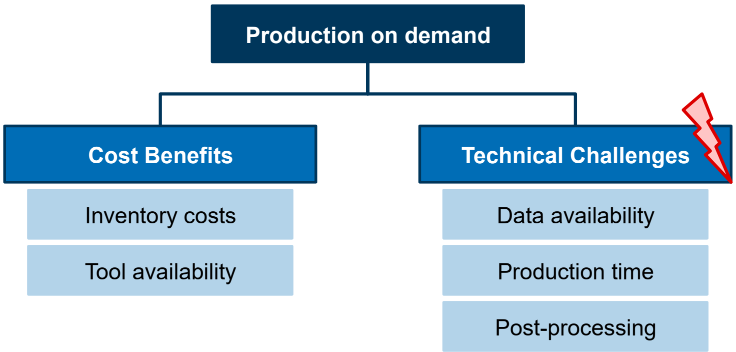

Figure 4-2: Benefits and Challenges of Production on Demand

It was already stated that logistic costs play a minor role in the spare parts provision process, which is one reason why production on location is currently not on top of the agenda of automotive OEMs. In contrast, production on demand offers **cost benefits** that are more important both to OEMs and suppliers and these specifically relate to *inventory costs*. The review of literature revealed the decisive impact of warehousing expenses on a company's bottom line (Walter et al., 2004)(Rommel & Fischer, 2013) (Garrett, 2014). This was emphasised by industry experts, especially since AM could cure the problem of keeping both fabricated items and necessary tools in stock for long periods of time.[32] Hence, the difficulty of guaranteeing *tool availability* – which is currently an issue for many OEMs and suppliers – might vanish.

Although it is hard to quantify the impact of AM technologies on warehousing costs from today's perspective, the expert interviews showed that production on demand is an aspect that is of major importance to the people involved in spare parts provision for passenger vehicles. Nevertheless, it has to be stressed that fabrication of spares by request also faces a couple of barriers, which are elucidated below.

As far as **technical challenges** are concerned, *data availability* plays a vital role. Although this aspect is being discussed in greater detail in the next section, it has to be mentioned in this connection. Evidently, production on demand requires CAD-files of the spare parts that are to be fabricated. When it comes to manufacturing by request, provisioning time is a crucial factor. Thus, if the requested component has to be redesigned digitally in the first place, the *production time* will be negatively influenced.[33] For the remaining consideration, however, it is assumed that a digital model of the desired spare part exists.

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[32] "OEMs and suppliers have to keep tools in stock for ten years. For this period of time they have to be able to reproduce any given part on their production facilities. […] Utilising AM technologies would surely reduce complexity in this field" (Rommel, 2015).
[33] "If digital information are not available, additive production of a part does not make sense. I would go even further and say that simply replicating a part is not economically efficient in any case, but this is a subjective opinion related to spare parts for our products in particular" (Company A, 2015).

Against this background, the perfect vision of spare parts would look like this: A customer needs a certain part or module to be repaired or replaced. The dealership or authorised workshop requests the desired CAD-file from the headquarters that store all parts digitally. After the data is transmitted immediately, the workshop prints the demanded part locally overnight. As shown in the previous section, producing the part on location is difficult, but also the additive creation on demand is still problematic for two reasons. First, the generation procedure itself often takes several hours and second, *post-processing* has to be taken into account as well.

Especially when it comes to metal parts, the entire fabrication process is tedious. A technology expert from *3D Systems* stated: “If we are able to deliver a desired component within five working days, we are incredibly fast” (Felsch, 2014). It has to be mentioned that this quote refers to a metal part – which typically requires a longer treatment after its fabrication.[34] But also plastic parts are hardly producible overnight, especially considering the fact that the actual production time is directly proportional to the size of an item.[35]

The previous sections tested the often-proclaimed benefits of AM technologies in terms of production on location and on demand. By means of empirical data through expert interviews it was illustrated that most advantages that are mentioned in literature are unlikely to hold true in practice. According to the prevailing opinion amongst specialists, a highly decentralised fabrication of automotive spares fails due to quality assurance constraints and excessive investments that would be required. In contrast, the benefits of producing spare parts by request are both more realistic and promising. Nevertheless, reaching a scenario in which “ready to use” spares can be produced on demand still requires some technological and business model progress.

While several scholars examined the impact of AM technologies on spare parts supply chains, most papers touched limitation only briefly or neglected possible drawbacks entirely. Hence, the present article fills this gap and elaborates on the potential strategic impact of AM technologies for the automotive aftermarket in the light of the findings that were articulated above.

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[34] “Metal parts need post-processing, e.g. stress relief heat treatment” (Felsch, 2014).

[35] “The larger the parts, the bigger the problems. […] It cannot be ruled out that parts are printed incorrectly, in fact, this still happens quite often. Although you can try to recycle the material, everything you produced is waste – expensive waste if it took you several hours to print it. Thus, if you have a large part that turns out to be unusable, a reprint of that part can easily jeopardise the profitability of an entire order” (Felsch, 2014).

Competitiveness of AM processes

The fourth and last sub-hypothesis stated that “AM technologies are competitive compared with conventional processes”. Answering the question of competitiveness requires the consideration of two distinct dimensions. On the one hand, the process has to meet technical standards and needs to be able to produce certain parts with recurring quality. If the technological aspect turns out to be feasible then, on the other hand, monetary issues can be assessed.

While a thorough investigation of technical constraints would go beyond the scopes of this paper, the focus will be on the economic efficiency of AM solutions for spare parts provision. Nevertheless, it shall be mentioned that industry experts attach equal importance to both the technical and monetary competitiveness of AM processes.

When talking about competitiveness, four situations have to be distinguished as illustrated in figure 4-3. The upper branch displays cases in which spare parts are directly produced by means of additive processes. In this connection, it has to be differentiated if a part was originally fabricated conventionally or if it was initially designed for additive production. In the former case, which is currently predominant in the automotive industry, it furthermore has to be determined whether CAD-files for the respective parts are available or not. Finally, the lower branch demonstrates parts that are produced conventionally with the help of castings, which in turn are fabricated additively.[36]

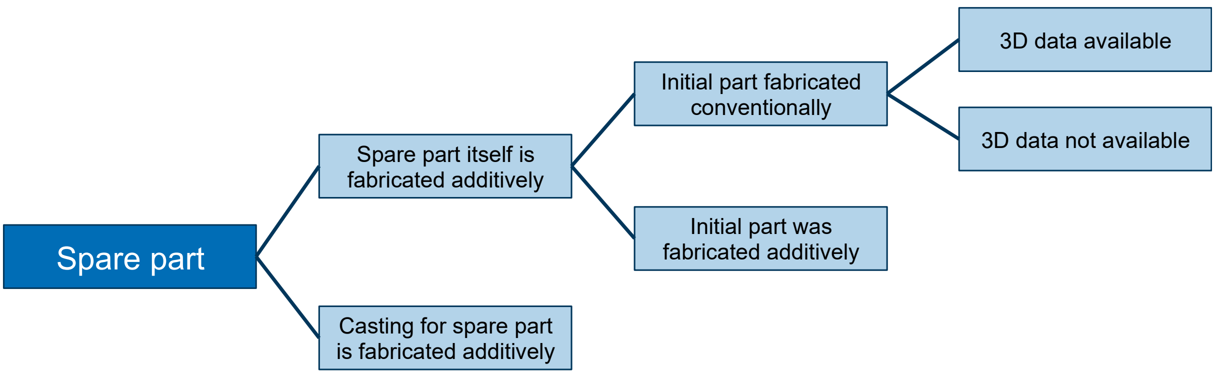

Figure 4-3: Initial Situations for Additive Production of Spare Parts

First of all, the upper branch with parts that were not particularly designed for additive production is being elucidated further, since the majority of components in a passenger vehicle are directly produced by means of conventional manufacturing processes. At this point it is relevant to consider the product lifecycle. If parts are designed

[36] Although casting parts constitute some 50-60% of the components installed in an average passenger vehicle, these parts are typically less relevant for the aftermarket (Santosi, 2009). Therefore, this branch is not being discussed in particular.

for conventional production and the product (i.e. a particular car) is still in its lifetime, the utilisation of AM technologies for spare part production evidently makes no sense. The relevant phase begins after the product's EOL when spare parts demand rises, while the initial product is not fabricated anymore.

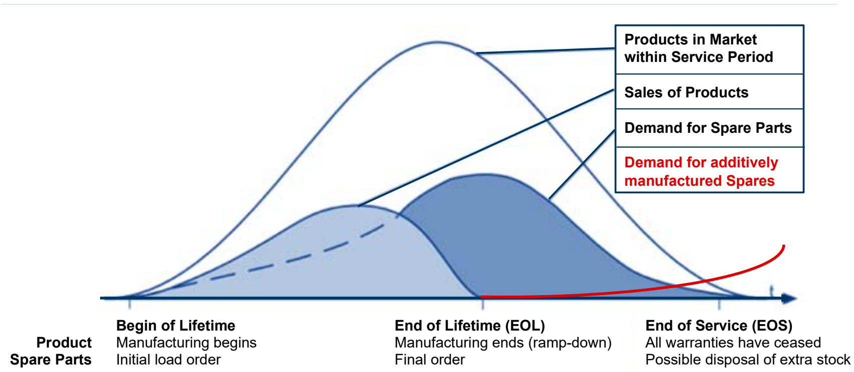

Figure 4-4: Product Lifecycle with Demand for additively manufactured Spares

Especially after the EOS when warranties have ceased, additively manufactured spare parts might gain importance in the future, according to industry experts (Baader, 2014) (Rommel, 2015). However, the often-mentioned example of classic cars – which are definitely beyond the EOS point – also entails a problem. Currently, technical information for the majority of parts for vintage cars does not exist digitally (Finsterwalder, 2015). In the course of time, this problem will diminish, but from to-day's point of view it leads to a dilemma. The later the stage in the lifecycle, the more additively manufactured spare parts might be needed, but at the same time the likeli-hood of 3D data availability decreases.

The problem of non-existing CAD files is salient. Desired spare parts would have to be redesigned or reverse engineered, which is costly and time-consuming. At this point, a progress concerning the quality of 3D scanners might affect this scenario positively. At the moment, however, industry experts do not see economic efficiency in the case of missing 3D data.[37]

Assuming that digital information for parts is available, the situation is different. Some OEMs have already tried to assess the efficiency of producing spare parts additively as illustrated in the literature review on the 'DirectSpare' programme (DirectSpare, 2013). In this particular case of *BMW*, an interview with an expert who was involved

[37] See footnote 93.

in the study revealed that the company did not follow up on the results and focused on the optimisation of AM for prototyping purposes instead.[38]

Interviews with representatives of other OEMs yielded that most companies elaborated on AM technologies for spare parts production, however, a structured analysis of economic efficiency was only reported from one interviewed specialist. The said person asked to remain anonymous due to non-disclosure requirements of his employer, which is referred to as '*Company A*' in the present article. *Company A* does not operate in the market for passenger vehicles, but utility vehicles. Nevertheless, both quality and safety regulations as well as technical standards are comparable to those within the automotive industry, so that the production of spare parts is a relevant issue in this branch as well. Therefore, the results of the profitability analysis are sufficiently transferable.

Table 4-1: Profitability Analysis of AM Spare Parts

	Part 1	Part 2	Part 3	Part 4
Purchase per Part	**2,72 €**	**1,56 €**	**6,62 €**	**2,51 €**
Demand [1year]	500	2	12	16
Raw Material total	157,5 €	4,02 €	235,4 €	1.839,2 €
Electricity total	0,6 €	0,02 €	3,3 €	25,9 €
Maintenance	1,7 €	0,04 €	25,7 €	201,1 €
∑ Variable Costs per Part	**0,32 €**	**2,26 €**	**21,82 €**	**130,92 €**
Annual Profit[39]	**2.137,3 €**	**15,8 €**	**-142,9 €**	**-2.005,8 €**

(based on COMPANY A, 2014)

Table 5-1 illustrates four scenarios that were explicitly quantified by *Company A*. It is noticeable that the demand volumes are significantly lower than those typical for the automotive industry. Still, the analysis reveals interesting findings. *Company A* currently procures all four parts that serve representatively for a variety of components that were tested by a group of experts. From an OEM's point of view, this scenario is similar to the situation carmakers face, as they source the majority of the parts that are later assembled. Thus, the table shows current purchase costs and subsequently

[38] "After the DirectSpare project we decided to focus on the utilisation of AM technologies for prototyping purposes. […] From my point of view, procedural costs are not yet competitive and additive production of components, both serial parts and spare parts, still has to overcome internal and external obstacles. Thus, as of today, additively manufactured spare parts are a secondary issue in our 'centre of competence'" (Rietzel, 2015).

[39] Profit = dealer net sales minus cost; not including tooling cost savings & fixed cost for AM machine.

calculates the costs of additive production. It turns out that parts 1 & 2 are economically efficient as far as variable costs are concerned. The largest driver for profitability in this case was raw material, which was considerably lower in the first two examples. These were plastic parts while both part 3 & 4 were generated from metal powder. Other investigated parts were printed from hard rubber, but the material proved to be inoperative for practical purposes.[40]

In sum, the analysis showed that spare parts made of polymers are currently more likely to be manufactured additively. This finding stands in line with statements from other experts and will be taken up in chapter five (Finsterwalder, 2015) (Kuhn, 2015) (Caspar, 2015) (Rietzel, 2015).

Finally, it has to be said that no interviewed OEM currently uses additively manufactured parts for series production – at least no parts that could be replaced. Thus, the case in which the initial part was fabricated additively was not explored in further detail.

The chapter at hand was meant to investigate if AM technologies have a strategic impact on the automotive spare parts business by discussing four sub-working hypotheses. At first it was shown that from a theoretical point of view additive fabrication has the capability to transform the aftermarket significantly. In a following step, statements from technology and industry experts served as empirical evidence to elaborate on the practicability of potential benefits arising from additive spare parts production. It became apparent that the vision of decentralised production faces major barriers, preventing it from establishing within the automotive aftermarket. Similarly, spare parts production on demand still suffers from technological drawbacks; however, industry experts attached considerably more importance to a 'fabrication by request scenario' than to the idea of production on location. Finally, both technical and monetary competitiveness of AM, compared to manufacturing by primary forming, forming, or cutting processes, was evaluated. The analysis particularly focused on economic efficiency and revealed that from today's perspective it is more likely that plastic spare parts are being produced additively than components made from metal.

With regard to the overarching working hypothesis, it can be concluded that AM technologies still have to overcome great obstacles before they are able to transform the automotive spare part environment. Nevertheless, the analysis showed that a change process according to the 'General Management Navigator' was initiated, be-

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[40] As stated in the body text, all information about the study came from an employee who asked to remain anonymous. Therefore, the paragraph abandoned direct quotes from said person.

cause OEMs and other players within the aftermarket intensified their research in this field. Considering the accelerated technological development during the last decade, it would be negligent to strike this topic from the strategic agenda. On the contrary, despite or precisely because of existing barriers it is crucial for OEMs to work on possible scenarios of AM utilisation for spare parts purposes strategically, in order to secure a potential first mover advantage.

Therefore, the next section elaborates on the strategic positioning with particular focus on automotive OEMs.

4.2 Strategic Positioning

While the previous sections analysed the significance of additive fabrication for the automotive aftermarket in general, the present chapter focuses on the different groups of players in particular. As illustrated above, the interacting market participants are the car making OEMs, first-tier suppliers, AM equipment manufacturers, and new market entrants. Other than that mentioned, technology and industry experts (i.e. academic scholars and specialised consultants) were interviewed, because of their opinion-forming role in the early stage of technology diffusion (Attewell, 1992). Interviews with representatives of each of these groups are being discussed separately in the subsequent sections.

OEM Perspective

Evidently, the most important players within the automotive aftermarket are the carmakers themselves. Even though the majority of parts come from suppliers, the OEMs still decide which parts are being procured from a particular source. Therefore, this first sub-chapter discusses interviews that were conducted with AM specialists working for automotive OEMs. Again, any information obtained includes subjective opinions so that the empirical evidence does not reflect official company statements, but rather individual expert knowledge. Given the above-mentioned fact, it is difficult to draw conclusions from particular interviews and generalise findings to such extend that they hold true for a company as a whole. Nevertheless, the interviews revealed insights into internal structures – either firm specific or general – that are being discussed in this section. In the light of the above, interviews with employees of each OEM are being reviewed separately, before a summarising analysis of the OEM perspective will be presented.

The most consistent rejection of AM deployment for spare parts purposes came from representatives working with the British carmaker *Jaguar Land Rover*, which is in line with findings that were recently presented by Reeves and Mendis (2015).[41] Although the company is "currently looking at additives", demand for additively manufactured spare parts is seen as irrelevant for the core business (Mitchell, 2015) (Bellamy, 2015).

[41] "The technology [AM] will not reach finish qualities that are necessary for our business. […] In my opinion, AM will not be a relevant issue for after sales in the next decade" (Bellamy, 2015).

As already mentioned, the German luxury carmaker *BMW* participated in the European DirectSpare program, but decided to primarily focus on AM for other purposes (Rietzel, 2015). Nevertheless, the company established a 'rapid technologies centre' that unites AM know-how for different applications along the entire value chain. In this connection, the utilisation of additive technologies for spare parts is certainly on the radar, although company experts stressed the remaining barriers.[42] Representatives of *Audi* expressed similar concerns and expressed the need for an increased process reliability (Caspar, 2015). However, the person interviewed explicitly emphasised that *Audi* is constantly investigating the potential of AM for after sales purposes and that AM facilities are operated internally to test possible applications.

At *Daimler Benz* the competence for AM series production, and thus also additive spare parts fabrication, is organisationally linked to e-mobility. While this structure is surprising, it makes sense when thinking about possible weight advantages. Two industry experts mentioned that weight typically plays a minor role for passenger cars (Finsterwalder, 2015). Hence, a key strength of AM production is almost irrelevant for automotive OEMs, which probably impedes the diffusion of this technology. In contrast, the aerospace industry heavily relies on lightweight structures, because less weight equals less fuel consumption and thus lower operational costs. For the automotive industry, this is currently significant when it comes to motorsports or luxury sports cars at most, but certainly not for average passenger vehicles. In future, however, e-mobility will gain importance for a wide range of OEMs and as long as battery runtime is limited, extended range could be reached by reduced weight (Finsterwalder, 2015).

Another interesting insight was gained from interviews with employees of the largest European car manufacturer *Volkswagen*. *VW* established a technological community that continuously elaborates on possible applications for AM technologies. Since this community is spread across different sites in Germany, it is not as centralised as *BMW*'s 'rapid technology centre', but it still illustrates *VW*'s awareness for additive technologies (Ricken, 2015). Indeed, *VW* was the only OEM that reported a real case in which a spare part was manufactured additively.[43] It was also mentioned that *MAN*, a sub-brand of *VW* producing trucks and utility vehicles, recently got a budget

[42] In particular the named challenges were: "Robust production processes; established total quality management process chains; sufficient reproducibility; customer satisfactory surfaces; proof of material lifetime sufficiency; extension of batch size economics; and part properties covering the requirements" (Woellecke, 2014).

[43] "Our after sales team at Bentley had to provide a spare part for which tools were unavailable. […] We've benefited from our close collaboration with experts from the Fraunhofer Institute, who helped us print this metal part. […] This is the only case of an additively manufactured spare part I am aware of" (Ricken, 2015).

for research on additively manufactured (spare) parts, which makes sense, considering the smaller volumes in that business. Thus, it seems as if *VW* is pretty much up-to-date with its efforts to identify possible applications for AM technologies and it also appears as if spare parts are part of the agenda.[44] Nevertheless, an interview with another employee conveyed a diametrically opposed semblance. Said person reported that: "The idea of additively manufactures spare parts is not bad, but *VW* will never install such parts" (Schauerte, 2015).[45] This statement came from a director of corporate research, who is responsible for materials and manufacturing processes at *VW*, which illustrates an interesting phenomenon of technology diffusion in large companies. Especially when it comes to disruptive innovations, there are different assessments amongst employees, which is particularly important at a higher management level. ROGERS (2003) described this scenario in his work on 'diffusion of innovation' and mentioned 'lead users' or 'opinion leaders'. It is questionable if AM technologies will ever establish as a suitable manufacturing technique for automotive spare parts, however, without people who believe in the advantages of such a novel technology chances of a successful implementation are poor.

Taking all individual statements into account, it emerges that most OEMs do not pursue the issue of additively manufactured spare parts aggressively. Despite the mentioned drawbacks in terms of quality and process liability, this is an interesting result and it displays the current strategic orientation of automotive OEMs. Judging from what the interview partners said, OEMs do not see the obligation to develop and refine AM technologies for purposes of series production.[46] Instead, a central role in overcoming current obstacles is attributed to suppliers. In how far these companies try to leverage the advantages of additive production will be discussed in the next section.

Supplier & AM Equipment Manufacturer Perspective

As just mentioned, OEMs see supplying companies in the lead to improve practical applicability of AM processes for automotive (spare) parts. At this point it is crucial to understand the supply chain structure and to analyse how this network might transform under the influence of emerging additive technologies.

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[44] *VW* currently employs a student who internally investigates the potential of AM technologies for spare parts, which underpins this assumption.

[45] Uttered concerns included approval processes, supplier relationships, etc.

[46] "As long as suppliers have not certified additive processes, we will not be able to procure additively manufactured parts. […] From my point of view, it still takes several years until our suppliers will be able to offer individualised parts at reasonable costs […]" (Rietzel, 2015).

Traditionally, supplying companies in the automotive industry face fierce competition, which is why economic efficiency is a pivotal concern for these firms. This situation typically impedes the early adoption of new technologies as long as their suitability is not proven as it is the case with AM processes (Rogers, 2003). Hence, it is not surprising that most inquired companies were unable to name possible experts, simply because AM is not yet a relevant issue; the *German Association of the Automotive Industry* underpinned this fact (Hella, 2015).[47, 48]

However, it is becoming increasingly apparent that new players enter the market and plan to establish as authorised suppliers for the automotive industry.[49] It turned out to be unlikely that traditional suppliers transform their production processes and implement additive technologies, instead, AM equipment manufacturers and companies that used to offer rapid prototyping services aggressively, try to produce final parts (Rietzel, 2015).[50] Since the latter group is very fragmented and the focus of the present article is on strategies for OEMs, only AM equipment manufacturers were interviewed as representatives for emerging suppliers of additively manufactured spares.

In this regard two of the biggest AM equipment and software companies, *3D Systems* and *Materialise*, gave insights into their spare parts strategies. A first interview was conducted with a business development manager at *3D Systems*, who predominantly focused on the fabrication of metal parts. As far as current barriers are concerned, the expert reinforced the findings that resulted from dialogues with OEM specialists. Quality issues, high costs, missing 3D data, and extensive post-processing were mentioned as major challenges (Felsch, 2014).[51] Yet in contrast to the OEMs, AM equipment manufacturers are much closer to AM systems engineering and its progress, so that a more optimistic view on the potential of AM utilisation for spare parts purposes emerged. Although the said interview partner was also sceptical about production on location scenarios, he could imagine a centralised fabrication of additively

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[47] "Both the 'department aftermarket' and the 'technical department' currently do not investigate the deployment of additive technologies for authorised automotive suppliers" (Ghirodi, 2015).
[48] Given the limited scope of this thesis, only larger first tier suppliers were contacted.
[49] Only companies that offer parts are being considered. Thus, suppliers of raw material for AM processes are explicitly not within the scope of this paper.
[50] "We [Materialise] produce plastic parts for aerospace, automotive, and railway applications. […] While our current focus is on non-functional plastic parts, we increasingly print visual components and just acquired expertise in processing aluminium and titan, so that metal parts are being tackled in the foreseeable future" (Kuhn, 2015).
[51] "When processing metal powder, you often face the problem that standard material like common tool steel cannot be used for AM systems. Thus, you are forced to opt for alternative metals that typically have superior properties, because you have to guarantee the robustness of a printed part. However, these materials are much more expensive, which results in increased prices for additively manufactured parts" (Felsch, 2014).

manufactured spares.[52] However, it is currently not planned that *3D Systems* runs such a large spare parts centre independently (Felsch, 2014). This fact underpins the need for a long-term oriented strategic positioning.

In this connection, *Materialise* seems to be one step ahead, as the company currently applies for certifications in order to become tier-one supplier for aerospace, automotive, and railway OEMs.[53] This fact illustrates the strategic impact of AM technologies not only on the automotive (after-) market. New players and suppliers transform the structures and OEMs have to elaborate on an optimum positioning that might involve new collaborations or even vertical integration in order buy and protect crucial technology know-how. The interview partner who works with *Materialise* as development manager for serial production emphasised that from his point of view carmakers do not put sufficient effort into this strategic challenge (Kuhn, 2015). While he also did not neglect existing barriers, target orientation appeared to be more aggressive.[54] This holds true along the entire value chain of additive spare parts production, which is depicted in figure 5-1.

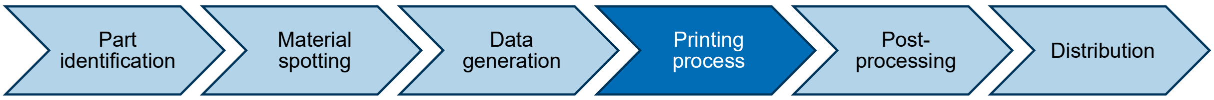

Figure 4-5: Value Chain of Additive Spare Part Production

Materialise tackles not only the actual printing process, which is often targeted by OEMs.[55] Instead, the company starts with developing a detection system that identifies potential parts for additive production. Subsequently, material spotting turned out to be a relevant issue as well as data generation, especially if CAD-data is not direct-

[52] "I do not believe in a highly decentralised additive production in the next couple of years. In order to be economically efficient, each AM system needs a high utilisation and from today's point of view this cannot be secured if you run dozens of machines across a country. […] Large spare parts centres could easily operate with multiple machines at the same time since required operation efforts are low. Thus, labour costs are moderate […]" (Felsch, 2014).
[53] Certification for railway is advanced, while audits for the other two industries are scheduled for late 2015 (Kuhn, 2015).
[54] "Manual post-processing is still a problem […]. We work on two different fronts; on the one hand, we try to optimise spotting mechanisms that help us to identify parts and materials that can be produced additively. At the moment we have to discuss each part individually, which is both time and cost consuming. On the other hand, we try to automate post-processing. While existing CAD-files help us to print parts easily, post-processing – especially milling – still requires manual programming. […] The additive generation process itself is actually pretty decent. Although companies request higher build rates, we are currently able to meet the demand without delay" (Kuhn, 2015).
[55] "After participating in DirectSpare, we decided to follow an holistic approach" (Kuhn, 2015).

ly available.[56] While *Materialise* particularly focused on plastic parts in the past, aluminium and titan application will soon be added to their range of offerings.[57]

With regard to automotive spares, the interview partner does not expect OEMs to produce parts themselves.[58] Instead, he reported that from his point of view independent suppliers would offer additively generated parts in the future. He also referred to production on location and was the only consulted expert that sees potential in this idea, particularly because "our clients want AM technologies to allow decentralised production, and in my career I've always observed that customer demands are fulfilled sooner or later" (Kuhn, 2015).

Taking the above-illustrated interview results into account and bearing in mind that other AM equipment manufacturers offer similar production services, it appears as if these companies are more likely to be those who overcome the current obstacles of additive spare parts production.[59] In how far this impacts the strategic positioning of automotive OEMs will be discussed after the perspective of independent expert has been illustrated briefly.

Independent Perspective

Not only industry representatives, but also independent specialists were interviewed and the results of these dialogues are presented in the present section. Most experts came from academia or consultancies – in any case they provided opinions that were not influenced by corporate interests of automotive OEMs or suppliers. Thus, they provided a form of outside perspective, which objectifies the strategic analysis.

First of all, several independent scholars emphasised the potential benefits of AM technologies for after sales applications; not only those cited in the review of literature, but also the experts that were consulted for the purpose of this article (Baader, 2014) (Klemp, 2014) (Langefeld, 2015) (Steinhilper, 2014). With regard to the automotive industry, however, ROMMEL stressed a misguided public opinion. In an interview he stated: "Despite the perception that automotive OEMs are highly innovative

[56] *Materialise* offers an in-house scanning that allows to digitalise any given component. The system's software is integrated so that subsequent CAE processes can follow immediately (Materialise, 2015).
[57] *Materialise* currently fabricates some 600.000 plastic parts per year. While the expert anticipates this business to remain a core competence, metal parts will be produced as well. However, he stressed that materials like aluminium and titan are more important in aerospace where weight reduction is a more central issue as already indicated in the previous section (Kuhn, 2015).
[58] "Automotive OEMs increasingly concentrate on design and development of functional parts [e.g. engines, gear units, etc.], while the actual production is outsourced. […] I believe in new authorised suppliers that offer additively manufactured spare parts" (Kuhn, 2015).
[59] Other AM equipment manufacturers like *Stratasys* (http://www.redeyeondemand.com/) or *EOS* (http://www.eos.info/) can be named representatively.

companies, the industry per se is actually very conservative when it comes to novel manufacturing technologies" (Rommel, 2015). This impression was indeed conveyed by most interlocutors working with OEMs.

The reason behind this fundamental reticence towards production technology innovations is the increasing importance of economies of scale. Successful carmakers rely on highly efficient production procedures that guarantee consistent quality at the lowest level of costs. Every change to the optimised operational processes entails uncertainties and is thus scrutinised with a sceptical eye from the risk avers OEMs (Rommel, 2015). Consequently, ROMMEL does not see the carmakers themselves in the role to utilise AM techniques for spare parts production, although he considers this positioning as a possible mistake. This view concurs with opinions uttered by most independent experts (Klemp, 2014) (Gissler, 2015).

Moreover, STEINHILPER (2014) mentioned another inhibiting factor that might impede OEMs from developing own solutions to AM utilisation for spare parts. In an interview he described that at the interface between technology innovation and after sales management two different worlds of thought are clashing together.[60] This holds particularly true in large corporations, since engineers and after sales executives are often separated, not only spatially but also organisationally. Hence, the creativity and inventiveness of technicians remain unconsidered when commercial decisions are being made.[61] Smaller companies, or those mainly employing engineers suffer less from this communication problem.

Finally, it shall be mentioned that specialised consultancies like *Barkawi Management Consultants* intensively try to support the diffusion of AM technologies within the automotive aftermarket.[62] In addition, interviews with larger strategy consulting firms were conducted and revealed insights that underpinned the already described situation (Gissler, 2015) (Langefeld, 2015). Experts see essential benefits in the deployment of AM technologies for spare parts. With respect to the automotive aftermarket, however, demand for additively manufactured spares was estimated low or moderate. Nevertheless, interviewed consultants anticipate persistent progress re-

[60] "AM is a rather novel production technology for the industry. […] Engineers that operate with AM facilities think creatively and they typically have geometric data and material properties in mind. In contrast, after sales managers often think operatively and constantly refer to numbers, lists, and catalogues. […] it is not easy to bring these two mind-sets together" (Steinhilper, 2014).

[61] This phenomenon was partially when different internal opinions within the *VW* group were presented and discussed.

[62] *Barkawi* is a consulting firm that has a specialised unit focusing on after sales and in this context particularly on the deployment of AM technologies (Baader, 2014).

garding AM systems technology, which extends the range of parts that might be printed in the future.

In summary, it can be emphasised that independent experts support the diffusion of additive technologies for the purpose of spare parts provision, either by delivering theoretical understanding of the technology or by providing assistance in implementing AM processes.[63] Yet it has to be mentioned that independent experts also stressed existing barriers which have not been explicitly mentioned in this section as obstacles have already been discussed.

Recapitulating the above illustrated perspectives, five possible scenarios for the diffusion of additive technologies into the automotive aftermarket emerged (see figure 5-2).

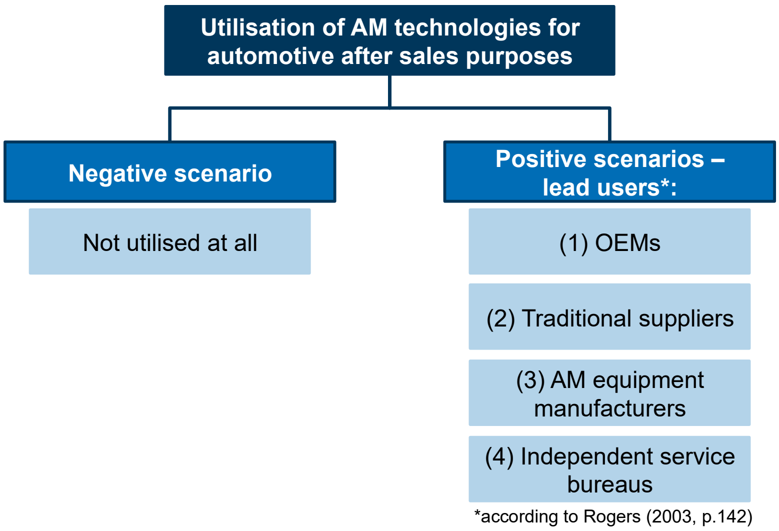

Figure 4-6: Scenarios for AM Utilisation within the Automotive Aftermarket

First of all, it is imaginable that AM technologies fail to establish as a proper fabrication method for automotive (spare) parts. Given the existing industrial drawbacks and disagreement concerning economically efficient business models, this alternative cannot be ruled out. However, regarding the lasting technological progress described by experts and considering the fact that the additive processes have already gained a foothold in other industries' after sales structures, it appears unrealistic that the technology will not have an impact at all. To what extend it remains a production method for niche application still has to be shown in the future.

Assuming that AM technologies are going to be implemented for after sales purposes, four different situations are conceivable as illustrated in figure 5-2 and evaluated

[63] It is assumed that consultancies operate with integrity and really believe in a successful deployment of AM within after sales structures.

in table 5-1. First, OEMs might produce spare parts by means of additive procedures themselves. Second, traditional suppliers might transform their production processes and adopt AM techniques. Third, AM equipment manufacturers might establish as new authorised suppliers, or last, independent service bureaus could offer to print parts that are demanded by OEMs. Each of the four scenarios was evaluated according to five pivotal factors and will be discussed below in order to support the strategic positioning of automotive OEMs in the light of emerging additive technologies.

Table 4-2: Evaluation of AM Scenarios for the Automotive Aftermarket

	Scenario 1 OEMs	**Scenario 2** Traditional Suppliers	**Scenario 3** AM equipment manufacturers	**Scenario 4** New / independent service providers
AM know-how	+	--	++	++
Existing network	/	++	o	--
Core competence	o	--	+	++
Innovativeness	o	o	++	+
Resources	++	+	+	-
Overall	o	-	++	+

The first scenario sees OEMs themselves in the role to produce spare parts by means of additive processes. Considering the fact that all interviewed OEMs already have a specialised unit for rapid prototyping in place, it is assumable that basic technology know-how exists. Above that, in-house production would shorten the value chain and reduce external coordination effort. However, as far as production is concerned, OEMs progressively focus on assembly operations, so that the actual fabrication of (additively manufactured) parts is no core competence.[64] Even though these large corporations would have monetary resources to install AM facilities either centralised or decentralised, the scenario appears improbable, taking the statements of interviewed executives into account.

In a second scenario, traditional suppliers could transform their production processes and deploy AM machines. While these companies already have an established business relationship with OEMs, it is unlikely that large suppliers will adjust their highly optimised processes in favour of a new and not yet fully sophisticated technology; especially since most of the OEMs' upstream suppliers do not have expertise in the field of AM.

[64] For this reason a vertical integration appears to be unrealistic.

Regarding the just mentioned technology know-how, AM equipment manufacturers certainly possess the largest amount of relevant expertise. Although the production of final parts is not their initial core competence, these enterprises increasingly work on this front. First orders for parts were reported in interviews and at least one system manufacturer strives for a tier-one supplier certification in the automotive industry. Although supplier relationships with OEMs are not yet established, a scenario, in which AM equipment manufacturers provide additively manufactured spare parts and assert themselves as authorised suppliers, is conceivable. In fact, it currently appears to be the most likely set-up, which allows OEMs to think about strategic alliances with large AM equipment manufacturers, or their specialised sub-brands.

The last scenario considers new market entrants or smaller service bureaus that supply OEMs with additively manufactured spare parts. While these companies already have expertise in printing components, most of these parts do not have to meet quality standards comparable to those in the automotive industry. Thus, audits would have to be performed with a very fragmented group of companies. This fragmentation would impede an easy cooperation with large automotive OEMs, not only because the bargaining power of each individual service bureau would be fairly low, but also from the OEMs point of view, considering the immense control and communication effort. A scenario in which small service bureaus supply OEMs would, however, come close to the vision of production on location. From a holistic perspective, however, such a constellation is unlikely to be economically efficient, unless new entrants are able to occupy a niche, like *Croft Additive Manufacturing*, for instance.[65]

All things considered, it is conceivable that additive technologies find their way into automotive spare parts production in the future. The four scenarios presented in this chapter illustrate possible set-ups and indicate a potential transformation within the automotive aftermarket. Even if the demand for additively manufactured spare parts will be limited in the next decade, it is crucial for OEMs to strategically think about chances and opportunities that might arise from emerging additive technologies.

[65] *Croft* produces filters, inter alia for automotive applications. The sub-brand *Croft Additive Manufacturing* launched recently and offers additively manufactured spare parts (Geekie, 2015).

5 Conclusion and future work

The article at hand addressed a gap in literature about the strategic impact of AM technologies on the automotive after sales business. In order to provide a basic technical understanding, state of the art AM processes were presented in chapter two. Above that, key aspects of modern spare parts management were discussed and related theories were reviewed. A comprehensive overview of the current automotive aftermarket illustrated the potential of AM technologies to transform this business by providing individualised spare parts on demand and on location without a necessity for expensive tooling. However, the subsequent analysis of these potential benefits revealed that neither the idea of spare parts generation by request nor highly decentralised fabrication structures are technically feasible from today's point of view. Nevertheless, additive technologies entail advantages that will definitely affect the automotive aftermarket in the future. New market entrants offer additively manufactured spare parts through online auction platforms, thus underpinning the demand for rapidly fabricated components.Leading automotive OEMs still attach limited importance to additively manufactured (spare) parts due to particularly high quality standards that are not yet fulfilled by most additive processes. This holds especially true when it comes to high quantities. However, parallel developments in the field of e-mobility or environmentally friendly production might support the significance of AM processes for final part manufacture.

Although current technical barriers impede the technology from establishing in this particular automotive after sales environment in the short-run, possible medium-term scenarios are foreseeable. Thus, from an automotive OEM's perspective it is just the right time to elaborate on a sustainable strategic positioning.

Table 5-1: Key Findings

Key Findings
AM technologies have the theoretical potential to affect the automotive aftermarket, although there is no reason to expect a short-term disruptive transformation
Propagated benefits in terms of 'production on location' and 'production on demand' still have to overcome substantial obstacles in practice
Automotive OEMs are not anticipated to print spare parts themselves, instead operator models appear to be more likely
AM equipment manufacturers and independent service bureaus have the potential to establish as authorised suppliers of additively manufactured spare parts
Despite the current barriers to additive spare parts production, automotive OEMs have to position themselves strategically in the next years

Research Limitations

The article at hand is explorative in nature and therefore includes limitations concerning statistical generalisability. Although a wide range of experts was interviewed, the individual statements can neither be collectively exhaustive nor can subjective opinions be representative for entire companies, as the conducted interviews were not coordinated with respective press departments.

Concerning the objectivity of presented findings it can be said that the present article sought to exclude subjective bias associated with single-person research to a maximum extent. This particularly applies to interviews that were conducted for the purpose of this paper. Candidates were chosen carefully, but generalisability of the information provided might be limited. Especially with regard to questions addressing strategic orientations of particular companies it is unclear to what extend interviewees were able to disclose all relevant information.

While the article tried to give a comprehensive overview on a strategic level, selected aspects were ignored. It was attempted to indicate disregarded issues either in body text or footnotes. Due to the complex situation of AM deployment within the automotive aftermarket, however, overlooked influencing factors cannot be completely ruled out.

Future Research

Future research is recommended to address above-mentioned research limitations and ensure more generalisability of the findings. Based on the obtained empirical evidence on technological constraints, new theories concerning AM utilisation for spare parts provision in the automotive industry should be developed.

Given the early stage of technology diffusion, the proposed set-ups of AM deployment are to be tested critically. In this regard, it would be interesting to find out if automotive OEMs are able to manage a knowledge-transfer from rapid prototyping to rapid manufacturing or if indeed operator models are the most likely scenarios for the future.

Moreover, an increasing awareness of sustainability, not only regarding the use of passenger vehicles but also their production, might affect the importance that is being attached to additive (spare) part production. Thus, an analysis of interdependencies between AM utilisation and parallel developments, e.g. in the fields of electric mobility, might be advisable.

Above that, synergy effects may result from an increasing demand for tailored products. Individualised or modified spare parts could be generated additively, thus leveraging the potential of mass customisation.

In general, future research can apply more focused and differentiated regarding analysis of the interface between AM technologies and spare parts production.

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