CHALMERS
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# Distributed Production of Spare Parts Using Additive Manufacturing

## Opportunities and Challenges for Volvo Group

*Master's Thesis in the Master's Programme Supply Chain Management*

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# Abstract

## Introduction
It is argued that challenges facing the automotive service market could be relieved with the help of additive manufacturing (AM) owing to its flexibility and possibility for low volume production. AM could also enable production of parts closer to the point of demand through distributed production, which aims to shorten the supply chain. Volvo Group wants to explore distributed production in relation to the company's service market supply chain. The purpose of this study is hence to contribute to the understanding of the effects of distributed production using additive manufacturing of spare parts at Volvo Group.

## Methodology
This study had a qualitative focus with quantitative elements. Firstly, an investigation in to the background of the study was performed, from which the purpose, research questions and the scope were defined. Following were a literature review and empirical data collection. The findings were then compared and contrasted in the analysis, from which conclusions were drawn.

## Theoretical Framework
The theoretical framework supported and guided the data collection. Recent published literature on AM and distributed production was compiled, to establish an understanding for the general opportunities and challenges with the technology combined with distributed production. Established literature on spare parts in the automotive industry and on supply chain management was furthermore reviewed to apply the previously described theory to Volvo.

## Empirical Findings
The empirical data collection methods of the study included: Internal and external interviews regarding the current supply chain structure at Volvo and the viability of AM and distributed production, Internal and external study-visits and workshops related to the development of AM, Correspondence with AM service providers and Data accessed through internal systems to enable a case study.

## Analysis and Results
From the theoretical and empirical findings, six potential opportunities and six potential challenges of distributed production using AM have been identified and are hence included in the analysis. The opportunities include: Improved supply chain reliability and flexibility, Reduced inventory related costs, Decreased transports, Reduced lead times, Increased service levels and Increased customization possibilities. The related challenges include: Network interdependencies and risks, Ownership and information management, Quality management, Digital infrastructure and copyright infringement, Organizational maturity and Return on investment.

## Conclusion

The study concludes that distributed production of spare parts using AM can be a long-term goal for Volvo, which is viable once the presented challenges can be sufficiently managed and the AM technology and supply market have developed. A gradual and iterative process of increased AM maturity and understanding of the benefits, but most importantly of the limitations, of AM and distributed production are important in Volvo's continued AM adoption.

Key Words: Additive Manufacturing, Distributed Production, Distributed Manufacturing, Spare Parts, Service Market, Supply Chain Management, Automotive Industry

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# Abbreviations

3DP – Three-Dimensional Printing
AM – Additive Manufacturing
BOR – Back Order Recovery
CAD – Computer Aided Design
CDC – Central Distribution Center
DC – Distribution Center
RDC – Regional Distribution Center
SC – Supply Chain
SDC – Support Distribution Center
SML – Service Market Logistics
VOR – Vehicle Off Road
Volvo – Volvo Group

# 1. Introduction

This is the report of a study regarding logistics strategies for distributed production of spare parts manufactured through additive manufacturing at Volvo Group. This chapter of the report begins with discussing the background and hence identifying the significance of the study. The purpose and related research questions are then motivated and followed with a presentation of the scope of the study.

## 1.1 Background

Additive Manufacturing (AM) is a manufacturing technology that has received increased public attention during the last decade (Gibson et al., 2017). With AM, products can be built up by adding layer-upon layer of material according to a digital three-dimension reference model (Rogers et al., 2016). The technology aims to handle the challenges an increasing amount of companies are currently facing with the growing demand for customized low volume products (Mellor et al., 2014). Kahjavi et al. (2013) argue that AM can help resolve some of these issues by enabling production of smaller batches, and Rogers et al. (2016) argue that each manufactured product can be unique.

One of the industries in which the technology has shown to bring benefits is the automotive industry (Gibson et al., 2017). The automotive company Volvo Group (Volvo) have followed the development and gained growing interest for how the technology could be applied in the company's supply chain, where spare parts has been identified as a promising area for increased AM adoption[1]. Spare parts, in comparison to other products, have sporadic demand and are hence more difficult to forecast (Li et al., 2017). They also tend to have higher unit costs and result in higher costs of stock-outs (ibid.). However, the aftermarket is of high importance for automotive companies, as it comprises a significant part of revenue streams (Cohen et al., 2006). Failure to provide a spare part when requested by a customer leads to a negative customer experience and costly down-time (Cohen et al., 2006). This can become expensive for and reflect poorly on Volvo.

Various AM ad hoc initiatives have already been taken in different parts of Volvo and resulted in a range of pilots being run. The focus has been on integrating AM in the current supply chain of spare parts, rather than develop the supply chain flow with the use of the specific characteristics of AM[1]. However, Volvo have now decided to proceed further with a more determined and coordinated AM approach owing to increased management focus on the technology and its vast possibilities. Various opportunities and challenges with AM are now being explored by the company and distributed production with the use of AM is one area which the company want to gain understanding in.

[1] Gerhard Kjellberg (Head of Material Planning, Volvo Group Trucks Operations) interviewed by the authors 29th of January 2018.

Distributed production with the use of AM could be used to produce spare parts closer to the customer, owing to the limited economies of scale of the production technique (Kahjavi et al., 2013). This is argued to enable elimination of supply chain steps and hence decrease non-value adding activities (Durão et al., 2017). Additional research within this area is necessary, as Rogers et al. (2016) call for more research on what effects AM can have on a supply chain, and Khajavi et al. (2014) identify a gap in the literature regarding AM and its enabling of distributed production supply chains.

Due to reasons described, Volvo now wants to understand how distributed production with the use of AM could contribute to the specific spare parts supply chain of Volvo, including what opportunities and challenges could be expected.

## 1.2 Purpose

Volvo Group wants to explore and understand the opportunities and challenges which distributed production using additive manufacturing of spare parts would entail, and what impact it would have on the supply chain. Based on this, the following purpose has been defined:

*The purpose of this study is to contribute to the understanding of the effects of distributed production using additive manufacturing of spare parts at Volvo Group.*

## 1.3 Research Questions

In order to fulfill the purpose of the study, two research questions (RQ) have been identified. The understanding of the effects of distributed production for spare parts using AM at Volvo, have been broken down in to two sub-categories. Firstly, the potential benefits are chosen to be investigated, in order to aid Volvo in determining whether a distributed production set-up with AM is of interest to consider. This is why the first RQ focuses on mapping and evaluating said opportunities, contributing to the sought understanding of the effects on the supply chain. The first RQ is hence defined according to the following:

RQ1: *What are the potential opportunities of distributed production using additive manufacturing for the spare part supply chain of Volvo?*

In order for Volvo to draw use of the potential opportunities, it is of significant value to determine and evaluate the possible barriers and challenges which distributed production using AM could incur. This contributes to the understanding of the applicability of the opportunities to different situations at Volvo, and could further aid in guiding the direction of Volvo's strategy in moving forward with AM. The second RQ hence considers these factors, and is defined as follows:

RQ2: *What are the potential challenges and risks of distributed production using additive manufacturing for the spare part supply chain of Volvo?*

The research questions will be tested, against theoretical and empirical findings, in chapter *5. Analysis and Results.* Section *5.1 Scenarios of Distributed Production* will compare and contrast the various levels of distributed production with the use of AM, which could be applicable for Volvo, in order to create a foundation for understanding the opportunities and challenges for the spare part supply chain. Section *5.2 Opportunities with Distributed Production of Spare Parts using AM* will then foremost correlate to RQ1, after which RQ2 will primarily be focused on in section *5.3 Challenges with Distributed Production of Spare Parts using AM*. The answers to the research questions will lastly be presented in chapter *7. Conclusion.*

## 1.4 Scope

Because of the relative newness of the AM technology, there is currently limited competence on the complete AM processes within Volvo. The strategy which is to be pursued in regards to a make-or-buy decision is not yet finalized, and could change in the foreseeable future. Hence, this study will not specifically discuss this aspect in depth or consider the impact of this decision to a great extent. Furthermore, as the study explores the opportunities and challenges of a distributed production set-up for Volvos service market supply chain using AM, it will not take in to account the profitability or applicability of AM as a technology itself. This is due to that several investigations in to this have already been conducted.

# 2. Theoretical Framework

The theoretical framework guided the collection of empirical data, and together with this supports the analysis and conclusions of the study. To answer the research questions, an understanding of the AM characteristics is necessary which entails its opportunities, challenges, the growth of the industry as well as future expectations, wherefore theory on these areas is provided. Further described are the opportunities and challenges of distributed production according to theory. These opportunities and challenges serve as a foundation for the analysis where the characteristics of AM are connected to the opportunities and challenges of distributed production. The theoretical framework also includes theory on the automotive spare parts industry as well as supply chain management, which will be used to understand the suitability for AM and distributed production in the specific case of Volvo's spare parts supply chain.

## 2.1 AM

AM is a technology which has gained great attention recently and it has already been applied in multiple industries such as in the automotive, aerospace and health care (Thomas, 2016). The technology started off as rapid prototyping (RF) with three-dimensional (3D) printing in the 1980s. Over the years, new applications and areas of use have been identified, wherefore the term Additive Manufacturing was developed, as it was no longer only about prototyping (Khajavi et al., 2014). Today, the term Additive Manufacturing is often used interchangeably with the term 3D-printing (3DP) (Thomas, 2016).

Gibson et al. (2010) explain that an AM process consists of eight phases. The first phase (1) *conceptualization and CAD*, involves making decisions regarding requirements and preferences for the final product and creating a CAD-model of the product. The next phase, (2) *conversion to STL*, is about converting the CAD-model into a STL-file which is a file format supported for most AM-printers. The following phases (3) *transfer and manipulation of STL file on AM machine* and (4) *machine setup* are to prepare the STL-file and AM-printer by deciding on parameters etc. used in the upcoming printing process (Gibson et al., 2010).

Once the preparation is performed, the (5) *build* phase can be initiated (Gibson et al., 2010). The printing is executed by adding layer upon layer of materials such as powder, metal or plastic, which finally results in a product according to the digital CAD-model (Miesel et al., 2016). This main process is common for different available AM techniques, among these are: laser sintering (SLS), direct metal laser sintering, fused deposition modelling, stereolithography (SLA), laminated object manufacturing and inkjet bioprinting (Li et al., 2017). However, the different AM techniques support different materials such as: plastic, metal, ceramics, glass, and paper. The input material can be powders, filaments, liquids or sheets, among other types (ibid.). Depending on a couple of factors such as the choice of product or quality requirements etc., the printing process can take from a few hours to a few days to finish (Miesel et al., 2016).

After the printing, the following phases can be initiated: (6) *part removal and cleanup*, *(7) post-processing of part* and (8) *application*. Excess materials needs to be removed and often a notable amount of manual post processing is necessary, such as polishing, sandpapering, painting or other activities depending on the preferences and requirements on the final product (Gibson et al., 2010). The eight steps included in the process described by Gibson et al. (2010) can be seen in Figure 1.

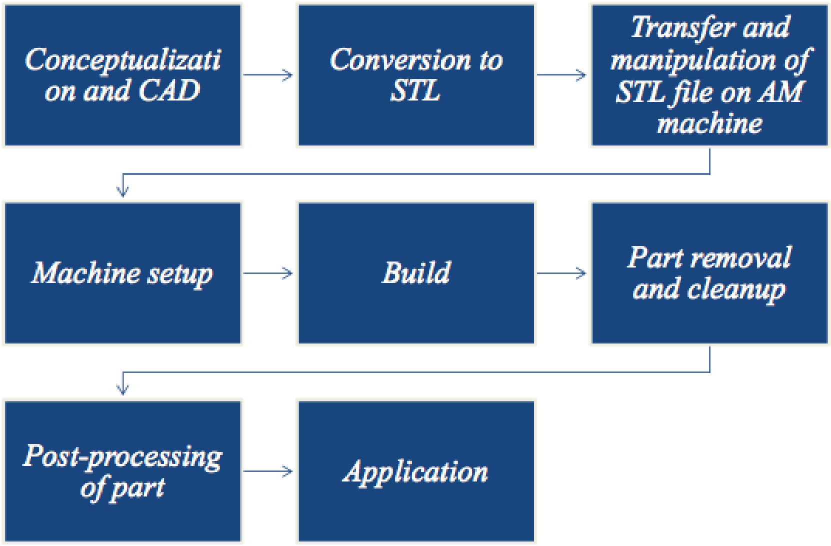


*Figure 1: Processes for AM, inspired by Gibson et al. (2010)*

### 2.1.1 Potential Opportunities with AM

The use of AM can provide other opportunities compared to traditional manufacturing processes. AM requires no or very limited tooling and there is low level of economies of scale (Li et al., 2017). AM is therefore commonly more economically feasible, than other traditional manufacturing processes, for production of customized and low volume products (Khajavi et al., 2014; Roger et al., 2016). Very complex product geometrics can be handled with AM (Khajavi et al., 2014; Roger et al., 2016) and a variety of materials such as: plastic, metal, ceramics, glass, and paper are supported by AM (Li et al., 2017).

Consequently, AM allows greater flexibility than many traditional manufacturing processes to the level that each AM-produced product could be unique (Rogers et al., 2016). This relates to the possibilities for product optimizations which are significant with AM and the fact that design changes could be quickly performed (Khajavi et al., 2014). Another opportunity relates to that less amount of material is commonly necessary with AM and the technology can produce grids and hollow products, which is beneficial when more light-weight products are desired (Oettmeier & Hofmann, 2016). AM also provides the possibility for part consolidation - parts which previously were manufactured separately could be manufactured in a single piece which could reduce the number of manufacturing processes (Oettmeier & Hofmann, 2016).

The characteristics for AM enable for manufacturers to in theory produce any product, at any time, at any location, as long as a CAD-file, materials and a printer are available (Khajavi et al., 2014; Li et al., 2017). Furthermore, if products could be manufactured closer to the customer both lead times and inventories could potentially be reduced (ibid.). A compilation of the potential opportunities with AM, described in this section (2.1.1), is presented in Figure 2.

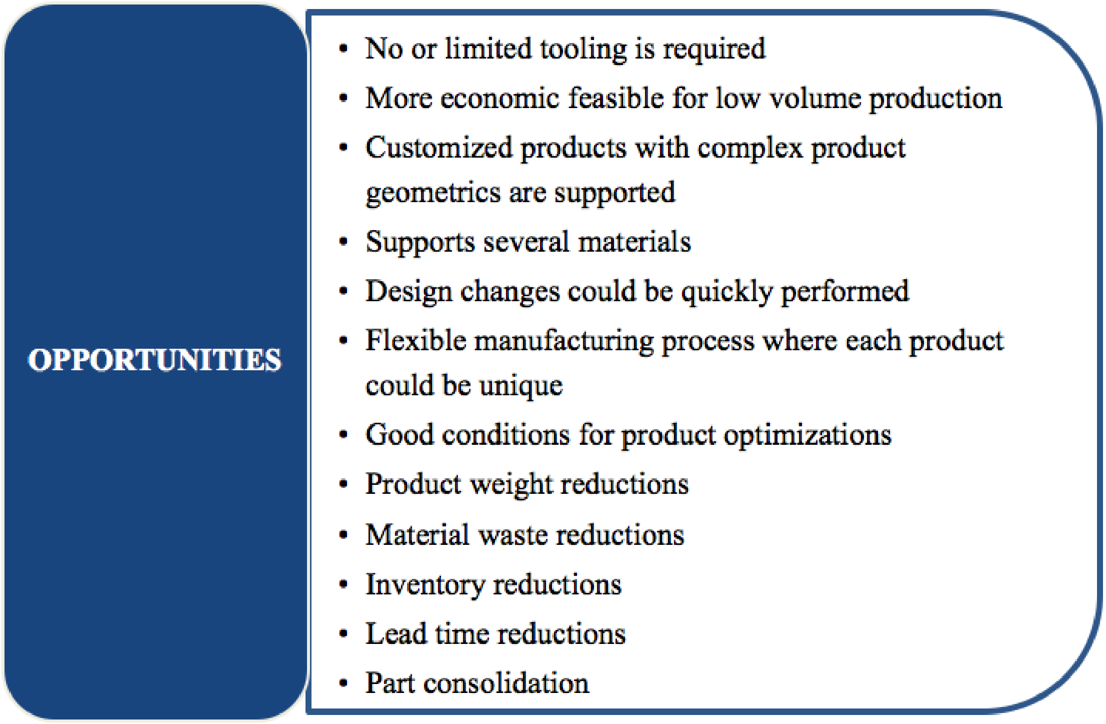


*Figure 2: Potential opportunities with AM*

### 2.1.2 Potential Challenges with AM

AM comes with challenges. As explained, the manufacturing technique is more beneficial for customized, low volume products while large-scale production of standardized products is still performed to a significant high cost and to a low speed with AM, compared to traditional manufacturing processes (Oettmeier and Hofmann, 2016). This relates to the high investments costs for the printers (Thomas, 2016). Another cost which according to research has shown to strongly affect the potential for AM is the material cost (ibid.).

The technical limitations of the printers are other concerns which affect the abilities when it comes to material choice, accuracy and quality (Durach, 2017). There are also technical limitations related to surface finish precision which impacts on the potential product range and need of post-processing (Oettmeier and Hofmann, 2016). Furthermore, since AM is a technology which has developed recent years the lack of experience and the organizational aspects are to consider (Rogers et al., 2016). A compilation of the potential challenges with AM, described in this section (2.1.2), is presented in Figure 3.

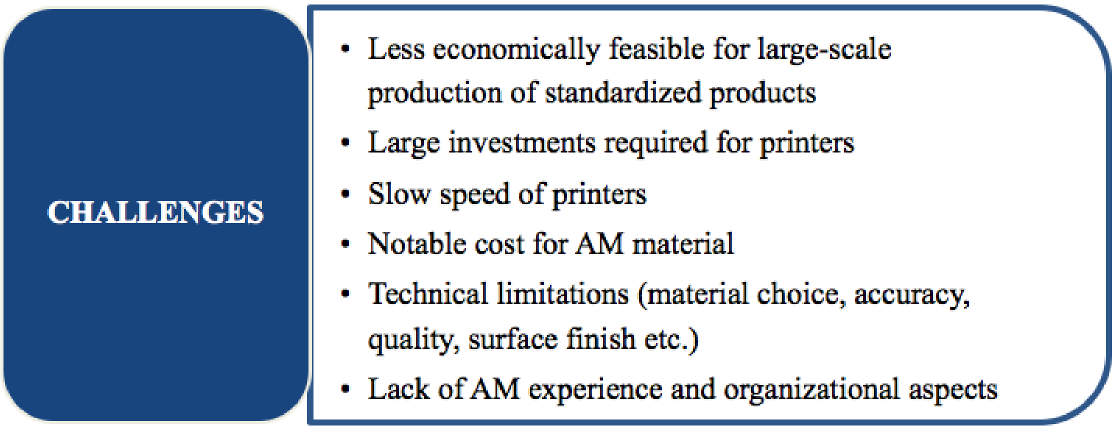


*Figure 3: Potential challenges with AM*

### 2.1.3 The Growth of the AM Industry

When considering AM and distributed production with the use of AM, companies need to understand the AM market, network and industry. Wohlers Associates is a consultancy firm which yearly publishes a report which entails a worldwide review and analysis of the AM industry (Wohlers Associates, 2018). 98 AM service providers, 51 system manufacturers, 15 third party material producers and co-authors in 33 countries contributed with information to the 2016 report (ibid.). Wohlers (2016) explains that there are several actors involved in the AM industry network amongst these: AM machine manufacturers, AM material providers, AM service providers and customers of AM products and services, see Figure 4.

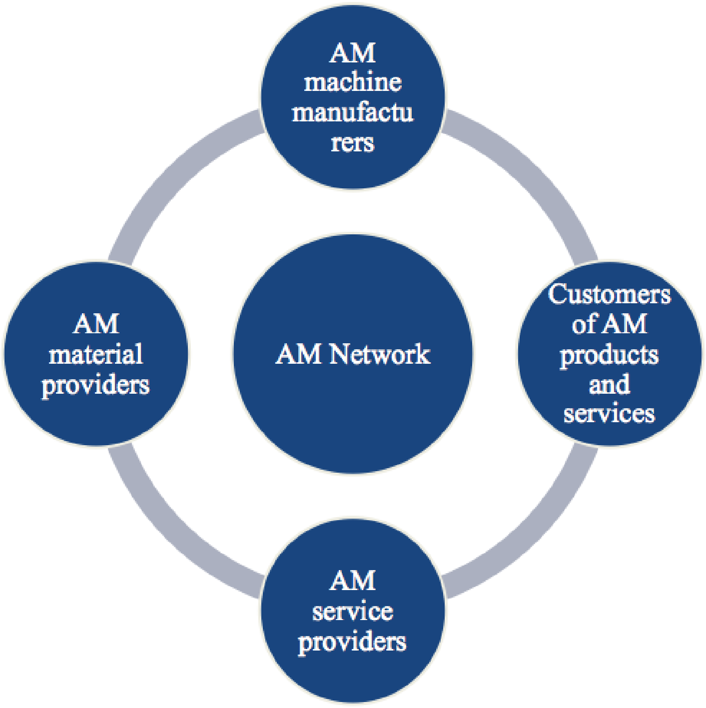


*Figure 4: Example of actors in an AM network, inspired by Wohlers (2016)*

According to Wohlers (2016) there has been a considerable industry growth which becomes visible when considering the increased sales of industrial AM systems, AM materials as well as AM part services. This could be related to three of the industry actors in the example AM network in Figure 4.

AM systems which are sold for $5.000 or more can be called industrial AM systems while those sold for less can be called desktop or low-cost 3D-printers. The number of sold Industrial AM systems has in average grown with 29.7 % each year between 1989 and 2015, however there has been some variation over the years. Thus, for the years 2012-2015 the average annual growth was 18.5 % (ibid.).

AM materials have also increased in sales which include materials as liquid, photopolymers, powders, pellets etc. (Wohlers, 2016). It is estimated that the sales of materials for AM systems amounted to $768.5 million in 2015 and $640.0 million in 2014, hence there was an increase of 20.1 %. The sales in 2015 for each material can be viewed in Figure 5. Metals are newer materials for AM which have been used about the last 15 years. The use of this material has had a rapid growth where the revenue from metals grew about 80.9 % in 2015, 49.4 % in 24014 and 30.9 % in 2012.

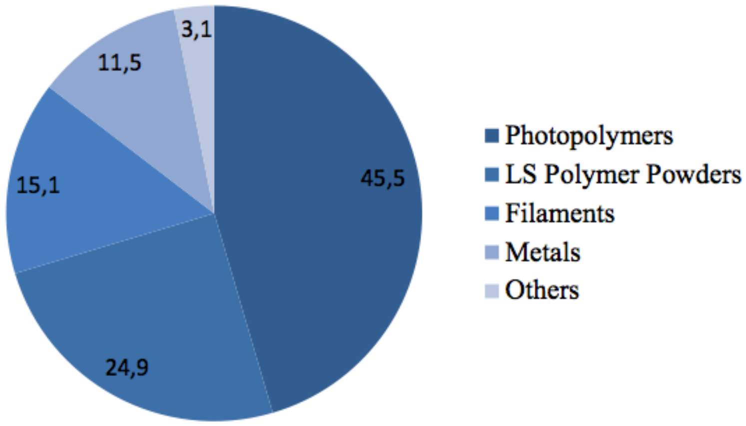


*Figure 5: The percentage of total sales per material in 2015, inspired by Wohlers (2016)*

AM part services have had tremendous growth in sales the last couple of years (Wohlers, 2016). It is estimated that the sales of parts produced with AM amounted to $1.714 billion in 2015 for the service providers worldwide. However, excluded here is AM's market for tooling (manufacturing of molds, dies etc.) and areas as designing and engineering. Comparing this to 2014 when the sales amounted to $1.307 billion, shows on an increase of 35.1 % from 2014 to 2015. The same trend can be seen previous years as the increase was 35.1 % in 2014, 21.1 % in 2013 and 24.2 % in 2012. A service provider could be individuals selling AM produced parts from one 3D printer as well as global companies who owns more than 100 AM machines and sell AM produced parts globally (Wohlers, 2016). Wohlers (2016) argues that due to this sales trend and added capacity by service providers recent years, continued growth for this segment should be to expect.

Wohlers (2016) also brings up a trend of AM machine manufacturers entering the service provider market. Actors which historically have focused on the manufacturing of AM machines have in cases taken up the competition against their customers by taking on the role as service providers; hence work in two markets simultaneously, impacting on the AM network.

### 2.1.4 Future Expectations on the AM Industry

The future expectation on AM is to consider for companies evaluating investing in AM and distributed production. One of the world's leading companies within research and advisory, Gartner, is providing its hype cycle where technologies' maturity and level of adoption is graphically illustrated (Gartner, 2018). A special hype cycle for 3DP was published by Gartner in 2017 (3ders, 2017), see Figure 6. A number of the mentioned expectations could be related to companies in the automotive spare parts industry, and three of them are described below.

According to the 3DP hype cycle, 3DP in automotive is climbing the slope (Gartner, 2017), see Figure 6. In this phase in the Gartner hype cycle, a technology's ability to contribute in a wider scope is more known and understood (Gartner, 2018). Higher generation products are commonly available, and more companies are investing in pilots (ibid.). 3DP in the automotive is expected to be less than two years away from mainstream adoption (3ders, 2017).

The 3DP hype cycle by Gartner (2017) it is also defined that 3DP in manufacturing operations is sliding into the through, Figure 6. This phase is characterized with increased attention for the technology, testing, experiments and implementations which are not yet successful (Gartner, 2018). Therefore, investments for further production improvements are necessary in order to satisfy early adopters (ibid.) 3DP in manufacturing operations is expected to be mainstream adoption in 2-5 years (3ders, 2017).

Currently, at the peak of the hype cycle is 3DP in supply chains (Gartner, 2017), see Figure 6. Early publicity is available which consists of a limited number of successful technology events but with even more failures (Gartner, 2018). A limited number of companies are continuing further with investments for improvements (ibid.). 3DP in supply chain is expected to be mainstream adoption in 5-10 years (3ders, 2017).

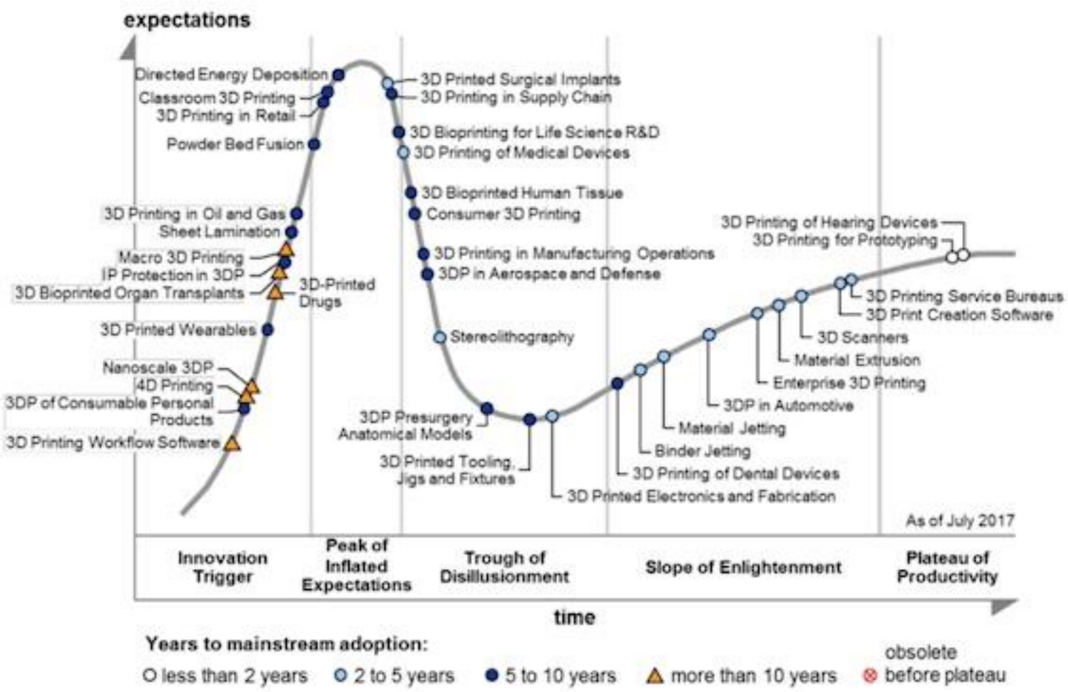


*Figure 6: Gartner's 3D-printing Hype Cycle (3ders, 2017)*

### 2.1.5 Drivers for AM Adoption and Implementation

According to Mellor et al. (2014), there are five factors which drive the adoption and implementation of AM within firms and are crucial to its successful implementation. The framework is illustrated in Figure 7. This framework will serve as a foundation for determining the factors of importance for Volvo to consider when moving forward with AM and distributed production.

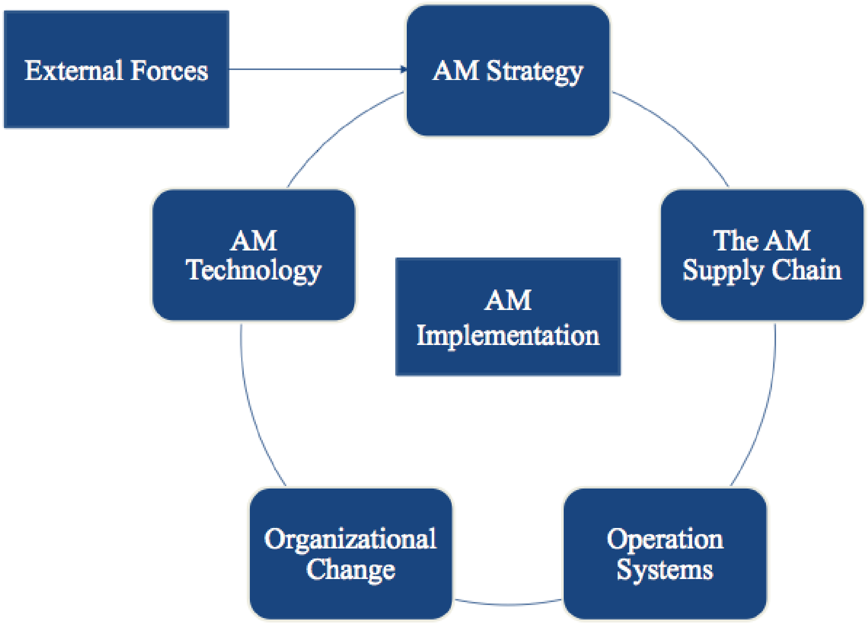


*Figure 7: Framework for AM implementation, adopted from Mellor et al. (2014)*

*AM Strategy* concerns to what extent adoption of AM aligns with overall company objectives, R&D strategy and business models (Mellor et al., 2014). *Technological Factors* are discussed regarding the significance of firms to understand the benefits and limitations of the technology itself, and be able to successfully weigh these against each other to provide realistic business cases. *Organizational Factors* concerns how a company must realize that implementing changes in manufacturing technology may prove difficult unless the correct re-structuring of tasks and ownership is done beforehand. *Operation Systems* concerns the changes required of the company's processes and administration in order to adopt AM. These include product design, production planning and control as well as quality assurance processes. *The AM Supply chain* refers to consideration of the different actors within the AM eco-system, where collaboration between parties may prove important. This aspect further covers the decision on where geographically the AM is to be performed. Additionally, *External Forces* such as customer demand, regulations and pressure from competitors will also come to influence AM adoption.

Bengtsson and Karlström (2017) argue that internal maturity in terms of AM technology is important for companies to consider, and will be a determinant for the success of adoption. The authors propose a framework for measuring firm’s maturity in AM adoption and value creation, which include strategic, organizational, supply chain, operational and technological AM maturity. According to the authors, supply chain maturity is important to consider due to the complexity of the AM eco-system and that successful AM adoption is dependent on a range of stakeholders.

## 2.2 Distributed Production

In order to determine the effects of distributed production of spare parts at Volvo using AM, it is of significance to understand the concept of distributed production. This section hence contains a theoretical review of the main characteristics and drivers of distributed production, as well as its potential opportunities and challenges. These characteristics, opportunities and challenges will continuously be connected to AM as a manufacturing technique, and a section of related case studies will then conclude the section.

### 2.2.1 Characteristics and Drivers for Distributed Production

Distributed production, also referred to in literature as distributed manufacturing, implies that the manufacturing of products is done at locations closer to the point of demand in a decentralized manner (Durão et al., 2017; Khajavi et al., 2014). According to Khajavi et al. (2014), there are two possible scenarios when companies decide on manufacturing location. In a centralized solution the world market is served from solely that facility, whereas in a decentralized solution, the production is carried out at different sites to serve different segments and markets (ibid). Main arguments for centralization include cost-efficiency and less complexity, whereas decentralization is more flexible and agile (Matt et al., 2014). According to Kohtala (2015), a central characteristic of distributed production is agility. Increasing demands on short lead times and customized products will lead to increasing focus on distributed production, as production must come to match the volatility of demand in a more reliable way (Matt et al., 2014).

Distributed production is not a new idea, but it has changed over time (Srai et al., 2016). The modern concept of distributed production is linked to multiple persons or sites being able to manufacture the same product in a codified way independent of location. This is driven by developments in engineering and computing, which contributes to increased automation and flexibility in production. One of the most important technologies in enabling distributed production is AM, through its potential in low volume and on-demand local manufacturing (ibid). Durão et al. (2017) also argue that to draw use of the potential opportunities of AM, such as reduced lead times and limited economies of scale, distributed production is a strategy worth considering. Distributed Production embodies a shift away from the long and linear supply chains associated with mass production (Kohtala, 2015).

Another key aspect of distributed production is according to Kohtala (2015) and Srai et al. (2016) the merging between production and consumption. The possibility for consumers to influence the production blurs the line between the two actors, and the concept of a "prosumer" may be relevant to consider (Kohtala, 2015). As technologies enabling distributed production to continue to evolve, products will become increasingly considered as data (Srai et al., 2016). This will draw use of the sharp growth of, and further strengthen the importance of, Big Data. The changing relationship between the consumer and the producer may create the opportunity for developing new business models (Kohtala, 2015).

Kohtala (2015) aims to map the current landscape of distributed production through a matrix, which can be seen in Figure 8. However, the four segments should be considered as overlapping, and more of a continuum than hard borders. The bottom left-hand and the top right-hand corner are the most prominent in current literature on distributed production.

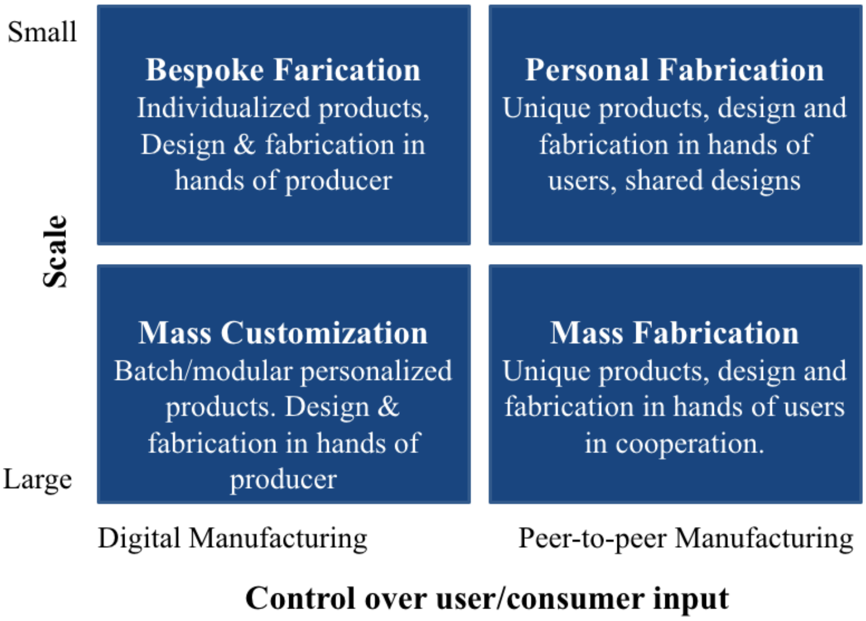


*Figure 8: The current landscape of distributed production, adopted from Kohtala (2015)*

According to Matt et al. (2014), there are seven drivers for distributed production, which will mean that it is a clear need for it in the future. The drivers include: 1. Sustainability: There is currently increased environmental awareness and customer demand for more environmentally friendly and produced products. This includes the demand for locally sourced and manufactured products to avoid the transportation from production to consumption. 2. Logistics Costs: Due to rising fuel prices and potential emission regulations, transport costs can soon become highly important to minimize. 3. Mass Customization: The growing demand for customization means that production facilities must be more flexible and produce lower volumes more economically. 4. Open Innovation: Technology advancements in for example AM leads to production opportunities which traditional factories may have difficulty competing with. The final drivers are: Customer Proximity, Resource Efficiency and Regionalism.

There can be various forms of distributed production, with different characteristics in terms of flexibility, location and aim (Matt et al., 2014). A compilation of these can be seen in Table 1.

*Table 1: Different forms of distributed production, adopted from Matt et al. (2014)*

| Nr. | Type | Characteristics |
|---|---|---|
| 1 | Standardized and replicable model factory | Geographically distributed production of defined products and number of units. |
| 2 | Modular and scalable model factory | Geographically distributed production of defined products but with a flexibility in number of units and scalability. |
| 3 | Flexible and reconfigurable model factory | Geographically distributed production with flexibility in terms of products and in number of units and scalability. |
| 4 | Changeable and "smart" model factory | Self-optimizing factories with high adaptability to geographically distributed production of products with similar processes in various volumes. |
| 5 | Service model of industrial contract manufacturing | Production service providers for distributed industrial contract manufacturing of different products with similar manufacturing steps in various volumes on for different clients. |
| 6 | Mobile and non-location-bound | Highly flexible and scalable factories for temporary production requirements reducing procurement and distribution. |
| 7 | Production Franchise | Geographically distributed production of defined products with more or less flexibility in number of units and scalability for supplying products in a franchise network. |
| 8 | AM in production laboratories (cloud production) | Highly flexible and geographically spread distributed laboratories for producing various products with AM processes by using digitally transmitted data. |

### 2.2.2 Potential Opportunities with Distributed Production

Potential benefits of distributed production include decreased inventory levels and related inventory carrying costs (Durão et al., 2017; Meisel et al., 2016). This may in turn improve firm profitability (Khajavi et al., 2014). Service parameters to customers are positively affected, as distributed production could lead to reduced lead time, increased service levels and therefore potential for improved customer satisfaction (Khajavi et al., 2014). Srai et al. (2016) and Matt et al. (2014) discuss the improvement in mass-customization possibilities, and Durão et al. (2017) highlight the improved ability to respond to changing customer demand. Srai et al. (2016) also emphasize the opportunities for quick and just in time deliveries due to local production.

Khajavi et al. (2014) and Durão et al. (2017) argue further that the supply chain can become more reliable, responsive and less sensitive. Production may become more resilient because of local material sourcing (Srai et al., 2016). Due to the increased flexibility which distributed production allows, it could alleviate some of the issues with unpredictable demand (Khajavi et al., 2014; Durão et al., 2017). Implementing distributed production may hence lead to a drastic improvement in the supply chain performance of spare parts (ibid).

Logistics is another area which distributed production may enable a cost reduction due to the reduced need for transportation (Durão et al., 2017; Meisel et al., 2016; Matt et al., 2014). Srai et al. (2016) and Matt et al. (2014) suggest that distributed production could, besides drastically reducing supply chain costs, improve the sustainability parameters of a supply chain. However, Kohtala (2015) argues that there is uncertainty in to what extent sustainability will improve. A compilation of the potential opportunities with distributed production, described in this section (2.2.2), is presented in Figure 9.

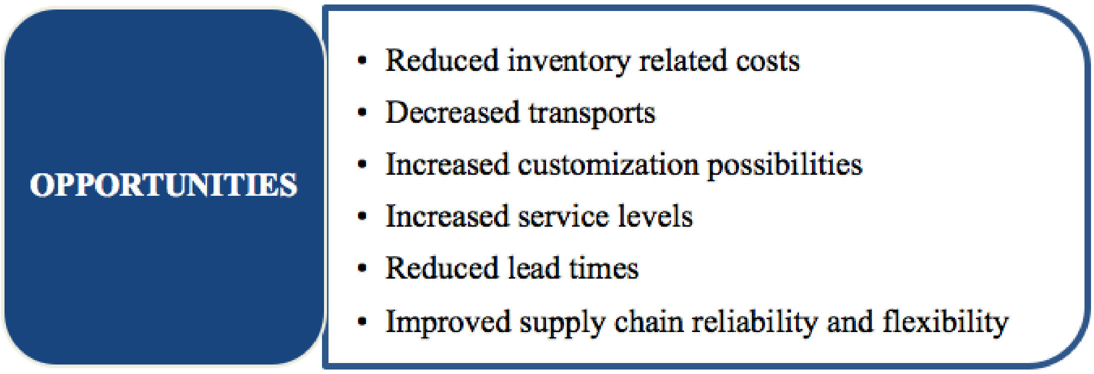


*Figure 9: Potential opportunities with distributed production*

### 2.2.3 Potential Challenges with Distributed Production

There are potential challenges with distributed production. According to Srai et al. (2016), governance and ownership questions are important areas for companies to secure when moving forward with distributed production. Furthermore, Durão et al. (2017) and Srai et al. (2016) highlight that companies may have issues with managing information between different productions facilities. Controlling operations in remote facilities may be difficult for firms. Khajavi et al. (2014) emphasize that a challenge in distributed production is the co-ordination and information exchange required by the involved parties. This co-ordination may become costly, as investments in building the digital infrastructure may require substantial investments (Srai et al., 2016). Global logistics implications may also occur due to infrastructural issues (ibid).

Srai et al. (2016) address the uncertainty of the financial returns of distributed production, due to the reduced economies of scale. The cost of assuring quality levels at distributed production sites may be high, as well as the costs and significant challenges involved with controlling the transport and delivery of products. Durão et al. (2017) emphasize the uncertainty of quality in distributed production, and where to allocate ownership of quality control.

Information security and control of intellectual property are further important aspects to consider when adopting distributed production (Srai et al., 2016). The authors discuss the integrity of a product in relation to this, and the need to protect against copyright infringement. The furthermore point out that standard and certification compatibility are areas which must be investigated to ensure regulatory and commercial viability. With unregulated distributed production, where 3D drawings are available to anyone, production anarchy may evolve. Factors such as liabilities and regulatory approval need to be considered. There is also uncertainty in how regulation and governance structures will develop (ibid). The need for regulation and control in this aspect is discussed by Durão et al. (2017). The implications of distributed production may furthermore lead to companies facing uncertainties in their business model and customer value proposition (Srai et al., 2016). A compilation of the potential challenges with distributed production, described in this section (2.2.3), is presented in Figure 10.

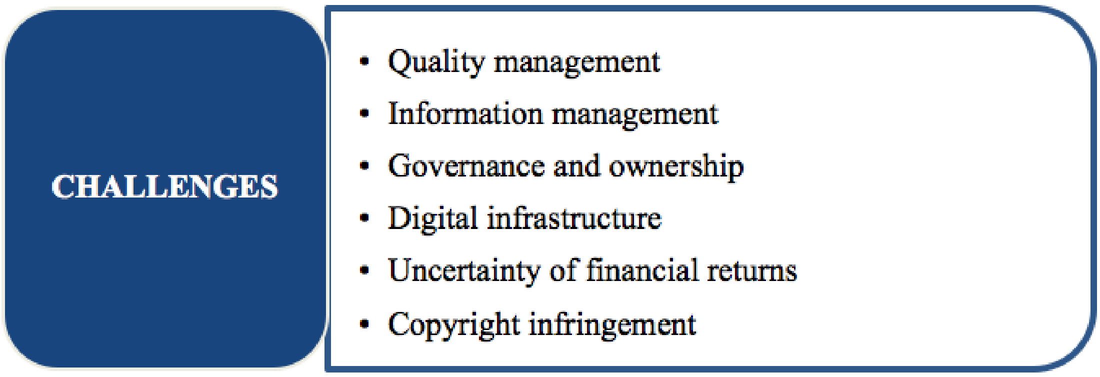


*Figure 10: Potential challenges with distributed production*

To overcome the challenges of distributed production, the literature presents several possible enablers and prerequisites. Srai et al. (2016) argue that distributed production will only become possible when the technological requirements are met. In terms of technology, it must be possible to create and sustain digital information and find a way of controlling it. According to the authors, the prerequisites for distributed production include: technological maturity, material understanding and control, monitoring and sensors as well as knowledge of the market in terms of suppliers and consumers (ibid).

Srai et al. (2016) furthermore stress the importance of digital infrastructure as an enabler and crucial element of functioning distributed production. Here, a risk assessment of information sharing must also be factored in. IT is highlighted as a major contributor to the future realization of opportunities by Durão et al. (2017). Srai et al. (2016) emphasize the importance of for example software and CAD-competence which enables the creation, modification and distribution of AM files.

### 2.2.4 Case Studies and Initiatives in Distributed Production

In order to gain an understanding for the various possible scenarios of distributed production and their applicability to Volvo, several case studies in to distributed production with AM have been identified. In a case study performed by Khajavi et al. (2014), the authors compare two in-house solutions: a centralized and a distributed production set up for the supply of AM produced spare parts of fighter jets in the United States, where AM facilities are located at the point of demand in the latter case. The study takes a total cost perspective including the cost of aircraft downtime, and also considers a future case scenario for improved performance and cost efficiency of AM machines. The authors conclude that when the study was conducted, a centralized set up was most beneficial from a cost perspective. This was primarily due to the distributed production requiring large investments in AM machines and their related personnel operation costs. The relatively slow rate of production limits the comparative advantage in time against transportation time from the centralized site. The centralized solution yielded higher transportation costs, inventory carrying and obsolesce costs as well as greater aircraft downtime (ibid).

In the future scenario of the case study by Khajavi et al. (2014) however, the assumptions lead to distributed production being a viable option not only when it comes to shorter lead times but also from a total cost perspective. The authors argue that barriers to distributed production are likely to decrease as the technical and financial aspects of AM machines improve in factors such as autonomy, quality and cost. However, it is important for companies to perform a cost benefit analysis before deciding on a distributed production set up, as there are different variables to consider for each industry and case (ibid).

Moreover, a case study performed by Durão et al. (2017) investigates distributed production of spare parts, where production information and requests are sent from a central factory to a decentralized production site. Various levels of control and regulation by the centralized factory is investigated. The authors conclude that the greater the independence of the distributed production sites, the higher the requirements are on efficient communication channels. This increases the amount of decisions in regards to quality which the distributed site has to take (ibid).

Another commercial initiative for enabling distributed production for firms is a partnership between an information system provider and external partners such as third-party logistics providers (Stackpole, 2013). The digital capabilities of the former are complemented with the AM capabilities and logistics network of the latter, where customers place an order which is then routed to the closest possible AM-hub and then shipped from there. The initiative aims to provide customers with an end-to-end solution for distributed manufacturing with AM, for them to draw use of previously discussed benefits such as lower inventories and agility in their supply chain. According to Stackpole (2017), this could hence enable customer companies to limit their investments in AM machinery while still realizing the benefits of localized production without the administrative or organizational complexity. Chalmers (2018) discuss the fact that surprisingly new players are entering the AM market, such as third-party logistics providers, who can draw use of their logistics network and use their hubs for AM.

## 2.3 Spare Parts in the Automotive Industry

To understand the opportunities and challenges of AM and distributed production in the spare parts industry, the specific context needs to be considered. Among companies, the spare parts business has become more important and the business has attracted more attention within supply chain management (de Souza et al., 2011). It is described that, historically, price and quality have been in the attention when companies have defined their offerings to customers, nowadays however, many companies have turned to focus more on offering customer value (Khajavi et al., 2014). This relates to the broader offering perspective, which includes additional services as keeping uptime for customers operations with high reliability (ibid.).

The aftermarket business is a high profit margin business and commonly accounts for a large part of companies' profits (de Souza et al., 2011). According to a study performed by Deloitte, revenues derived from aftermarket services commonly accounts for around 25 % of total revenues for companies (ibid.). The automotive industry is one of the industries where the aftermarket services have gained most attention. The products which automotive companies offer their customers are commonly characterized with long-life cycles. By supplying customers with aftermarket services and spare parts, the automotive companies could extend this life cycle further and hence plan to optimize the usage of high value equipment. By doing this, companies access an additional selling point and could focus on the increased value offering for already existing customers which could be less challenging than finding new customers to do business with (ibid.).

However, ensuring uptime for customer operations with reliability does not come without challenges. Spare parts, in comparison to other products, often have higher unit cost and result in higher costs of stock outs (Li et al., 2017). Furthermore, they often have a more sporadic demand and are hence more difficult to forecast (ibid.). Therefore, to ensure high fulfillment, companies often need to invest in costly spare parts supply chains, with large inventories, in many cases with slow moving products, close to the point of consumption (Khajavi et al., 2014).

## 2.4 Supply Chain Strategy and Network Design

Every company needs to set its supply chain strategy and network design to fulfil customer demand (Rushton et al., 2017). To understand how AM and distributed production can contribute to the fulfillment of customer demand it is necessary to understand AM and distributed production related to areas as supply chain strategies, network designs, performance measures, supplier portfolio management, supply chain risks and customer service at companies, wherefore theory on these areas are provided.

### 2.4.1 Supply Chain Strategy

A competitive strategy of a company can be defined by understanding what customer needs the company is aiming to meet relative to the company's competitors (Chopra & Meindl, 2016). Each function in the company and related function strategies must be aligned with the company's competitive strategy. This includes the supply chain strategy which entails how products are procured, how materials are transported, how products are distributed etc. (Rushton et al., 2017). To align the competitive strategy and the supply chain strategy, the supply capabilities and the demand uncertainties need to be understood as this relates to the level of responsiveness a supply chain should be designed for (Chopra & Meindl, 2016).

According to Rushton et al. (2017) products can be more or less of a "functional" or "innovative" nature. While the functional products are characterized by having a steadier demand and therefore more suitable in a cost-efficient supply chain, the innovative products are characterized by a more unpredictable demand which requires a more responsive supply chain (ibid.). Other aspects which need to be considered for deciding on a more efficient or responsive supply chain relates to the supply side where the potential lead time from suppliers is of importance (Christopher 2005; Rushton et al, 2017).

Lean and agile supply systems are commonly discussed related to efficient and responsive supply chains (Rushton et al., 2017). According to Rushton et al. (2017) lean policies are suitable for products with more predictable demand and can handle short as well as long lead time from suppliers in a cost-efficient way. However, for products that are characterized with more unpredictable demand agile policies are suitable when supplier lead times are short. In the case of unpredictable demand with longer supplier lead time, other or additional solutions may be necessary than just agile policies (Rushton et al., 2017). The reason for this is that agile policies in this context alone, might result in high inventories or lost sales due to mismatch between supply and demand. Therefore, Rushton et al. (2017) explain that additional or other solutions could be postponement solutions where the products final manufacturing processes are performed closer to the end-customer. The reasoning by Rushton et al. (2017) is visualized in Figure 11.

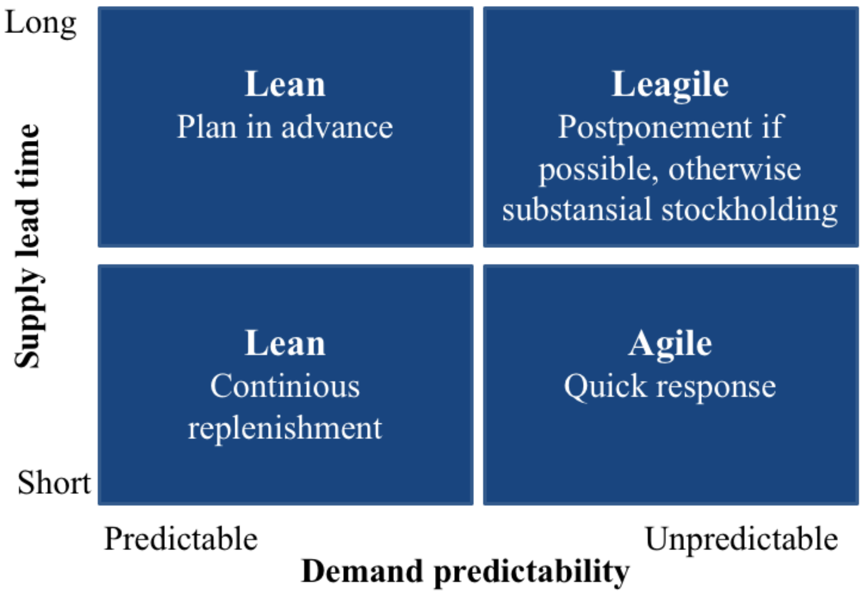


*Figure 11: Segmentation based on supply and demand characteristics, adopted from Rushton et al. (2017)*

Christopher (2005) states that the trend of increasing demand for customization and the shortening of product life cycles are factors leading to a need of more responsive supply chains. This relates to the reasoning by Bowersox et al. (2013) who explain that the use of push or anticipatory practices for products with more unpredictable demand could result in significant unplanned inventory. This is especially notable in a supply chain with many actors where each actor performs its own forecast and tries to secure its own interest and tries to reduce its own risks (Bowersox et al., 2013). By implementing more pull or responsive practices more information exchange, transparency and synchronization will be necessary in the supply chains. By doing so, lead times could be shortened, customization possibilities created, and inventory costs could be reduced (Bowersox et al., 2013). Hence, a more responsive supply chain could quickly respond to changes in variety and volume (Christopher, 2005). Rushton et al. (2017) relates this to the location of sourcing and argue that products with a more predictable demand could be sourced from low-cost countries while products with more unpredictable demand preferable could be sourced locally in order to keep lead time to a minimum.

### 2.4.2 Network Design

The design of a supply chain consists of determining the optimal number and location of various nodes, such as warehouses and manufacturing sites (Bowersox et al., 2013). Important questions to answer include which markets are to be served by which production plants and warehouses, and the inventory strategy at each warehousing level and their role in the chain. According to Rushton et al. (2017), geography is highly important aspect when designing a supply chain.

The supply chain network design also includes consideration of suppliers, service providers and all other stages of enabling the product to reach the end customers (Bowersox et al., 2013). Here, important questions include for example which sourcing and marketing channels to use. The design of a supply chain is often influenced by sourcing decisions, as for example off-shoring and distant sourcing will require different supply chain structures than locally sourced goods (Rushton et al., 2017). Rushton et al. (2017) argue that predictable demand may be met by sourcing from low-cost off-shore suppliers, while unpredictable demand may instead be met by using local suppliers to draw use of flexibility and reduce lead times. An example of a basic channel network structure can be seen in Figure 12 (Bowersox et al., 2013). A magnitude of further supply chain management decisions has to be taken at each of the levels, after setting the original network design.

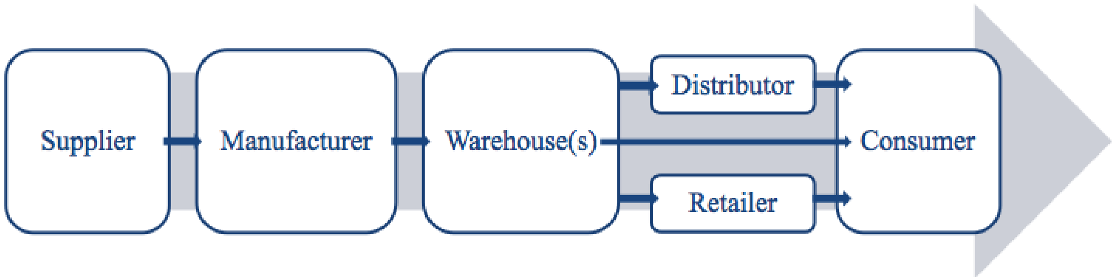


*Figure 12: An example of a channel network, adopted from Bowersox et al. (2013)*

High-performing supply chains need to adopt continuous improvement and consider how changes in customer demand, costs and competitors impact their strategy and operations (Bowersox et al., 2013). Regular analysis in to for example aspects such as inventory levels and freight solutions is vital to ensure balanced and efficient flows. However, supply chain analysis can be extremely complex, and involve a great amount of data. Advanced calculation tools are therefore used, to derive a mathematical optimization model (Bowersox et al., 2013; Rushton et al., 2017). Rushton et al. (2017) also state that planning a logistics network is a highly difficult task, and consider whether the main reason for why logistics flows are not balanced is because of the large amount of work required to understand and change a supply chain.

### 2.4.3 Supply Chain Performance Drivers

Chopra and Meindl (2016) have identified six drivers of supply chain performance. The choice of network design will have an impact on the effect of these drivers and hence supply chain costs. The drivers include:

#### *Inventories*

Inventories entail all the products and materials in their forms from raw material to finished goods in a supply chain (Chopra & Meindl, 2016).

### *Transportation*

Transportation includes all movement of products and materials through the supply chain to the point of use (Chopra & Meindl, 2016).

### *Facilities and Handling*

This driver includes all facilities in the network where production or storage takes place (Chopra & Meindl, 2016). The physical locations and the functions, capacities and potential flexibility are all factors impacting the supply chain and distribution performance (ibid.).

### *Information*

The information driver concerns all data and analysis related to the areas of the other supply chain drivers (Chopra & Meindl, 2016). Therefore, this driver could be argued to have the largest potential for influencing supply chain performance as it indirectly could affect all the other drivers.

### *Sourcing*

Sourcing includes the decisions of who is responsible to perform different tasks in the supply chain (Chopra & Meindl, 2016). These decisions can concern areas as production, storage, transportation and handling of information (ibid.).

### *Pricing*

Pricing is performed by actors in the supply chain and affects how actors are interacting with each other since it connects supply with demand (Chopra & Meindl, 2016).

The drivers of supply chain performance will have an impact on total supply chain costs (Chopra & Meindl, 2016). According to Petterson and Segerstedt (2013), there is room for improvement in the way that many firms measure supply chain costs. It is important to measure the performance of a supply chain, in order to ensure alignment with corporate strategy and find areas of improvement to ultimately improve the competitiveness of a company (Jonsson & Mattsson, 2009). Performance measurement is also a key aspect when considering a decentralized organizational logistical structure, to follow up on results and determining ownership.

One way of considering supply chain and logistics cost is through dividing them in to costs related to the material flow, or costs related to production (Jonsson & Mattsson, 2009). According to Jonsson and Mattsson (2009), the logistics related costs in a company can often amount to between 20 and 30 % of the price which a customer pays for a product. The material flow costs include: Transportation and handling, packaging costs, inventory carrying costs, shortage and delay costs and administrative costs. The production related costs include: capacity costs, production change costs and set-up costs.

### 2.4.4 Supplier Portfolio Management

Creating a balanced supplier portfolio strategy is key for companies, as different suppliers will be of different interests to companies (van Weele, 2014) and also dependent on the supply chain strategy Rushton et al. (2017). It is therefore of value to pursue an appropriate power-balance between the actors (van Weele, 2014). When determining what kind of supplier relationships to establish, it is of interest to consider the importance of the specific part in relation to the supply risk. The importance of a part can be measured through aspects such as total cost, volume and impact on business growth. The supply risk is measured through looking in to aspects such as product availability, number of suppliers, cost of changing suppliers, the market structure, substitutes and geographic distance (ibid).

Based on the aspects described above, products can then be segmented, and appropriate sourcing strategies can be pursued for each group (van Weele, 2014). There are four basic supplier relationships, with a range of different aims and levels of commitment. The strategies are, in falling level of commitment: Partnerships, Competitive Bidding, Secure Supply and Category Management/E-Procurement.

Moreover, purchasing and supply chain management has gained increasing attention from top management in recent time due to the growing specialization of firms (van Weele, 2014). This has in turn lead to increasing outsourcing, allowing firms to focus on core competencies (van Weele, 2014; Chopra & Meindl, 2016). There are however several risks with outsourcing, and these can be handled in two broad ways (van Weele, 2014). The first way to mitigate the risks of outsourcing is through partnerships based on trust, mutual commitment and communication. The other way of pursuing an outsourcing strategy is to establish detailed contracts. According to van Weele (2014) and Chopra & Meindl (2016), the risks with outsourcing include the following:

#### *Technical & Performance Risks*

This refers to the ability of a supplier to provide the requested products at the right quality and functionality. This also refers to the possibility that a supplier may not have the flexibility or capacity to maintain the necessary service levels or cost over time (van Weele, 2014).

#### *Commercial Risks*

Commercial risks refer to an escalation in price and other costs which may arise due to the outsourcing (van Weele, 2014). There is a possibility that companies lose touch with customers and the market through using an intermediary (Chopra & Meindl, 2016).

#### *Contractual Risks*

Contractual risks refer to the possibility of incomplete or inadequately created contracts (van Weele, 2014; Chopra & Meindl, 2016). Contracts are often formulated to incentivize suppliers, which may limit the positive effects from outsourcing (Chopra & Meindl, 2016).

### *Information Risks*

This refers to the possibility of sensitive information or intellectual property having to be transferred on to the supplier, which may knowingly or unknowingly leak this to competitors or other actors (Chopra & Meindl, 2016).

### *Dependence Risks*

This refers to the loss of internal competence which a company will experience due to outsourcing, and the possible dependence on a supplier which may occur as a consequence of this (Chopra & Meindl, 2016).

### *Co-ordination Risks*

This refers to the underestimation of costs which is often done by companies when it comes to estimating the transactional and costs of managing a dispersed supply chain (Chopra & Meindl, 2016). This may be especially difficult as the supply chain visibility is reduced through outsourcing.

### 2.4.5 Customer Service

According to Jonsson and Mattsson (2009), there are five performance variables which relate to customer service. These include: 1. Service stock level, relating to the number of orders which can be delivered directly to customers from stock, 2. Delivery precision, relating to the ability of companies to deliver in the agreed time frame. The authors argue that timely delivery is often just as, or even more, important than quick deliveries. 3. Reliability, relation to the proportion of correct orders delivered at the right quality. 4. Lead time, relating to the time from a customer order to delivery. 5 Flexibility, relates to the ability to respond to changing conditions in customer demand. In general, flexibility performance can be measured in regard to adaptability in the product mix, volume and delivery parameter. As these performance variables are of importance for customer satisfaction, they are hence also of direct impact on company revenue.

## 2.5 Conceptual Model

The theoretical framework has been constructed in order to guide the data collection of the study and to serve as a foundation for comparing and contrasting said data against theoretical models and findings. In order to fulfill the purpose of the study, to contribute to the understanding of the effects of distributed production using AM for spare parts at Volvo, the topics which were necessary to compile a theoretical framework in include: Additive manufacturing, Distributed Production, Spare Parts in the Automotive Industry and Supply Chain Strategy and Network. Distributed Production was considered in the AM specific context, wherefore theory on these two subjects are combined and summarized below. These are illustrated in Figure 13.

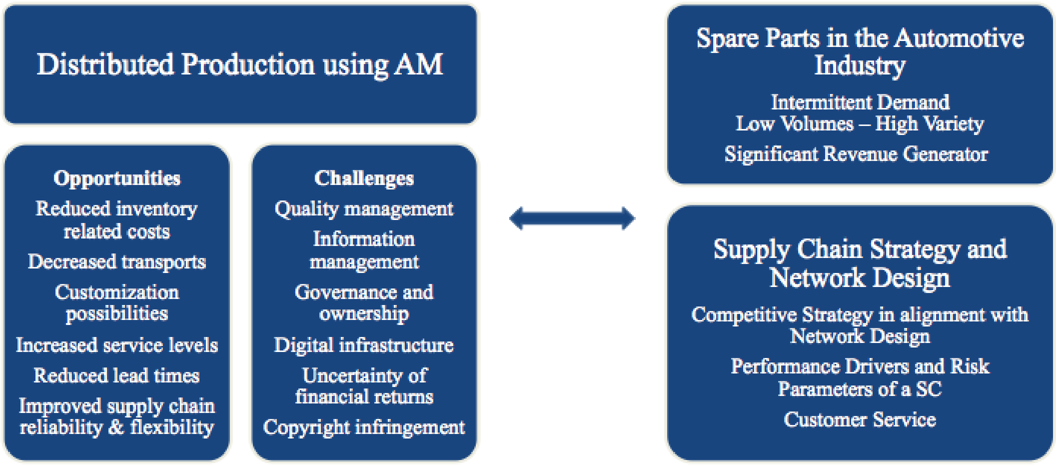


*Figure 13: The conceptual model of the theoretical framework used to guide the direction of the study*

As described in section 2*.1 AM*, there are several opportunities related to supply chain improvement, but also challenges such as costs and technological uncertainties, with AM. In addition, there are several areas which are important for companies to consider when adopting AM, such as the internal maturity and the interdependencies within the AM eco-system. Furthermore, the concept of distributed production and its various ways of execution is described in section *2.2 Distributed Production.* Opportunities such as improved service performance to customers and reduced inventories, and challenges such as information and quality management as well as governance and control, are emphasized. A list of the potential theoretical opportunities and challenges presented in sections *2.2.2 Potential Opportunities with Distributed Production* and *2.2.3 Potential Challenges with Distributed Production*, have been used as guides in the data collection and to form a foundation for understanding distributed production using AM in Volvo's service market context. These are also presented in Figure 13 above. They will be compared and contrasted against the empirical findings in chapter *5. Analysis and Results*, to determine the potential opportunities and challenges of distributed production using AM of spare parts at Volvo.

Section 2*.3 Spare Parts in the Automotive Industry* presents characteristics which are key to determining the effects of distributed production with AM for Volvo's specific industry. In addition, section 2*.4 Supply Chain Strategy and Network Design,* aids in determining the risks of different supply chain structures possible for Volvo when considering a distributed production set up, and how said structures impact supply chain performance. The data collection has hence been steered towards gathering information on Volvo's current spare part supply chain such as strategy and design, and other empirical information on case studies where different supply chain structures are considered. Furthermore, expert opinions on the viability of the supply chain structures and the supply side potential were investigated. This has been considered in terms of AM and distributed production, to connect the theoretical framework with the empirical data. Moreover, section 2*.4 Supply Chain Strategy and Network Design,* aided in determining the chosen variables which were considered in the case study and how these can impact supply chain performance.

# 3. Method

This chapter describes the methodology which was used to fulfill the purpose of the study. Firstly, the research strategy is presented, which was used to support the decisions of data collection and analysis methods and design in this study. Following are the various research methods and design, including interviews, data collected for the case study, workshops, study visits, review of internal documentation and a literature review. How data was treated and analyzed is then described before the chapter is rounded off with a description of the quality of the study.

## 3.1 Research Strategy

This study had a qualitative approach, with a supporting case study of both qualitative and quantitative nature which could be seen as a combined structure as described by Bryman & Bell (2003). Interviews were conducted with a qualitative focus in order to extract information to gain an understanding of the current state of Volvo's spare part supply chain, what role AM currently had in it and what the opportunities and challenges for distributed production with AM were internally and externally. The case study aimed to contribute to distinguishing the logistical differences between a distributed versus a centralized distribution strategy for a selected number of spare parts, where various levels of decentralization were considered. This entailed more concrete measurements and hence a quantitative nature. The investigation had a merging between a deductive and inductive approach, where theory was both tested against findings and where theory was also generated from conclusions of the research.

## 3.2 Research Method and Design

In order to establish the significance and steer the direction of the study, a background investigation was conducted. From this, the purpose, research questions and the scope of the study were established. A planning report was written in order to communicate and anchor the purpose, expected methodology and outcome with the University supervisor and the key stakeholders at Volvo.

To answer the research questions and thereby fulfill the purpose of the study various sources of information were considered. From the beginning, an understanding of the AM characteristics was deemed necessary and a prerequisite for understanding the effects of distributed production with the use of AM. Thus, the theoretical framework was initiated with theory on the technology AM and its opportunities, challenges, the growth of the industry as well as future expectations. The theoretical framework continues with the opportunities and challenges with distributed production. Due to the limited research available on distributed production and the limited number of case studies performed, interviews with external AM experts were performed in this study. Thus, the experts view on opportunities and challenges with distributed production serve as a complement to theory.

In order to evaluate an application of distributed production with the use of AM at Volvo, it was necessary to understand the current state of AM and distributed production at Volvo as well as the current state of the spare parts supply chain. Data about Volvo's use of AM and distributed production was collected from attending a cross-functional workshop on AM at Volvo, observing internal documentation, performing a study visit to an internal AM studio, and performing personal interviews with various company representatives which were involved in the topic. Information about Volvo's current spare parts supply chain was provided from internal documentation and interviews with internal actors with more specific knowledge of Volvo's spare part supply chain's capabilities and constraints. In order to analyze the effects of distributed production in a spare parts supply chain at Volvo, theory on spare parts in the automotive industry as well as theory on supply chain management were used as a base for strengthening the reasoning.

A limited number of Volvo spare parts were selected for a deeper analysis, as part of a case study. This case study aimed to illustrate a more concrete example of what the possible supply chain effects of distributed production using AM for spare parts could incur. Data of these spare parts and their flows was collected through internal systems at Volvo and interviews with internal actors. The parts selected for deeper analysis needed to be suitable for AM according to the criteria set by Volvo, wherefore the selection process was performed together with the company.

Additionally, a study visit to an AM research institute and correspondence with six AM service providers were performed in order include an external perspective of AM and distributed production, complementing the internal perspective. The theoretical findings and the empirical information were used as a foundation for the analysis of RQ1 and RQ2, see Figure 14. The identified opportunities of distributed production with the use of AM derived from theory and AM experts, and were analyzed with consideration of Volvo's AM spare parts supply chain. Also, identified challenges and risks derived from theory and AM experts, and were analyzed with consideration of Volvo's AM spare part supply chain. The spare parts selected for deeper analysis aimed to exemplify effects of potential scenarios of distributed production when compared to the current AM spare part supply chain. From the analysis, conclusions were drawn to fulfill the purpose of this study.

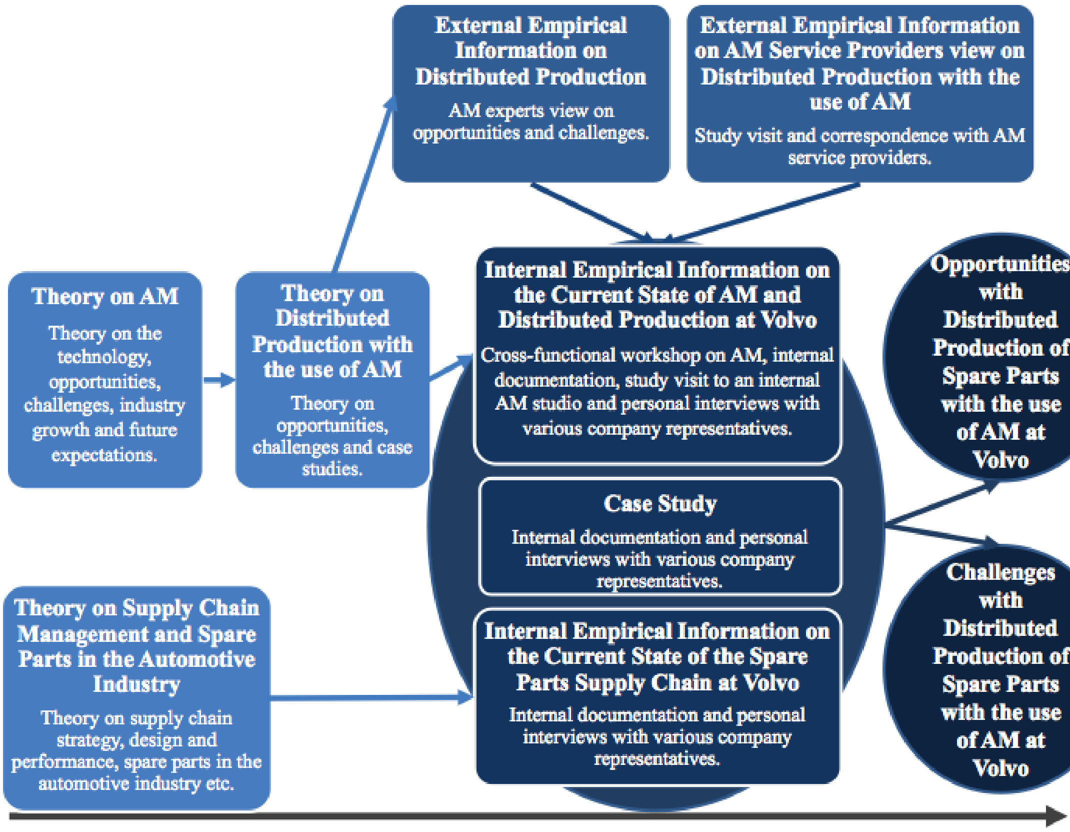


*Figure 14: A simplified linear illustration of how the research method supports the purpose of the study, which in reality entailed several iterative processes.*

### 3.2.1 Data Collection

This section describes the various forms of data collection which the study has drawn use of. These include: A literature review, interviews, a case study including accessing data from internal systems, study visits and attending workshops, accessing internal information as well as correspondence with suppliers.

#### *Literature Review*

A theoretical framework was constructed to form an understanding for the various topics included in the study, and to guide the data collection of the study. This entailed an iterative process, where literature was continuously reviewed during the study depending on the direction of the collected data, in alignment with the argumentation by Brewerton and Millward (2001). The literature search strategy was to start off in a broader scope, where a large amount of literature was briefly overviewed. After uncovering common themes and determining the suitability of the various theory to the scope of the study, the amount of literature was narrowed down as the scope of the study became more detailed. The narrowed down literature was then studied more closely, where focus was put on including highly cited material as far as possible. The trustworthiness of the literature was ensured to be high to as great extent as possible through scrutinizing the sources and publication responsible, and also through checking the sources for alignment against each other, as further recommended by Brewerton and Millward (2001).

The literature review contains theory on AM and on distributed production, as a cornerstone in understanding the core concepts related to the study. Due to the relative newness of the AM technology and especially distributed production, recent literature was considered in order to avoid obsolete facts being included in the study. Older information on for example AM technology was hence excluded. Following, literature on spare parts in the automotive industry as well as supply chain management was reviewed in order to determine the applicability of distributed production with AM for Volvo.

The literary study is mainly comprised of theory found through searches in scholar databases, including journals, e-books and articles. Physical books and internet research have also used been used. The main search phrases included for example "Additive Manufacturing", "3D Printing", "Distributed Production", "Distributed Manufacturing", "Spare Parts Automotive", "Supply Chain Strategy", "Supply Chain Network Design" and "Distribution Structure", as well as other similar phrases. The searches made have been both separate, in single areas, and also combined, for example AM and distributed production have been researched both separately and together to gain a broad and specific understanding of the concepts.

### *Interviews*

To gain a broad understanding of the current state of Volvo's spare parts supply chain, several initial interviews with employees were conducted. This was deemed highly important as it provided empirical data and served as a foundation for determining the possible next steps for potentially integrate the use of distributed production with the use of AM in the supply chain. After a broader understanding had been created, more in-depth interviews with appropriate subjects were conducted. These interviews were of a semi-structured nature, as described by Bryman and Bell (2003), with interview guides of formally prepared questions which were used in order to steer the direction of the interviews, while still allowing freedom to ensure that the interviewee could express other thoughts and ideas. This qualitative research was dependent on flexibility as it ensured that any views expressed were thoroughly investigated and that follow-up questions could be answered. An overview of the performed interviews can be seen in Table 2.

Furthermore, it was the ambition of the authors to conduct the majority of the interviews face-to-face in order to limit the possibility of misunderstanding, which aligns with the recommendations of Bryman and Bell (2003). All interviews were documented at proximity to the interview, and to situations where it was applicable, recording and transliteration were used. By doing this, the risk of context getting lost could be reduced and furthermore reduce potential misunderstandings which a time-delay may create. Interview questions can be viewed in Appendix II.

*Table 2: Interviews conducted in this study*

| Interviewee | Company | Date | Type of Interview | Use of Interview Information in this Report |
|---|---|---|---|---|
| Manager Material Planning | Volvo Group | 2018-01-30 | Face-to-face Semi-structured | 4.2.3 Material Planning Department |
| Manager Advanced Analytics | Volvo Group | 2018-02-01 | Face-to-face Semi-structured | 4.2.5 Advanced Analytics Department |
| Backorder Handler | Volvo Group | 2018-02-19 | Telephone Semi-structured | 4.2.7 Backorder Recovery Department |
| Refill Analyst | Volvo Group | 2018-02-21 | Face-to-face Semi-structured | 4.2.4 Refill Department |
| Senior Buyer | Volvo Group | 2018-02-26 | Face-to-face Semi-structured | 4.3.4 AM from a Purchasing Perspective |
| Manager European Service Center Nordic | Volvo Group | 2018-03-05 | Face-to-face Semi-structured | 4.2.6 Service Center and Transport Parts Management |
| Prof. in Surface Engineering, Researcher at the division of Materials and Manufacturing | Chalmers | 2018-03-22 | Face-to-face Semi-structured | 4.5.1 The view of AM and Distributed Production of an AM Expert at Chalmers |
| Business Development Manager | Volvo Group | 2018-04-05 | Face-to-face Semi-structured | 4.4.1 Background of Case Study |
| Group Manager AM | Swerea IVF | 2018-04-23 | Face-to-face Semi-structured | 4.5.3 The view of AM and Distributed Production of the Head of the AM Group at Swerea IVF |

### *Case Study*

In order to give a concrete example of what the possible supply chain effects of distributed production using AM for spare parts could incur, a case study was conducted. The case study consisted of mapping the supply chains of a selected number of spare parts determined together with Volvo, who are considering producing these parts with AM in an ongoing pilot for the Australian market. The case study aimed to aid in identifying the various transports, inventory costs and lead times related to the current state of the supply chain, and which could be reduced through adopting a distributed production set-up with AM for Volvo.

When mapping the supply chain of the selected spare parts, the various nodes of the supply chain as described by Bowersox et al. (2013) and described in section *2.4.2 Network Design* were considered, as these were deemed to cover the entirety of a supply chain. These nodes include the pick-up point from the supplier, the CDC in Gent, the RDC in Australia and the dealers in the Australian market. When choosing what data to consider for the mapping, the drivers of supply chain performance as stated by Chopra and Meindl (2016) described in section *2.4.3 Supply Chain Drivers* constituted the foundation of the mapping. Hence, two of the major areas of focus were transportation between the nodes and Inventory at and between the nodes, which was further deemed of interest as the theoretical framework for both AM and distributed production describes improvement possibilities in regards to these parameters. As all nodes are internal in this supply chain, mapping, Pricing was excluded. The drivers Facilities and Handling, Information and Sourcing were also considered, wherefore interviews to understand the information and control flows were conducted.

In addition, lead time as discussed by Jonsson and Mattsson (2009) in section *2.4.5 Customer Service* was deemed as a significant measurement, specifically since the theoretical framework for both AM and distributed production describes improvement possibilities in regards to this aspect. This data was then used to describe the supply chain of the parts with focus on throughput time, as a combined measurement of inventory and lead time, as well as transportation distance. The throughput time at the different nodes was calculated through the formula: Throughput = Inventory / Demand. Data concerning costs arising between and at the different nodes, such as warehousing and transportation costs, was sought extensively, but it was not possible for the authors to collect this data for the specific or similar parts.

The method of mapping the flow was inspired by the value flow mapping as described by Nash and Poling (2008), where the flow of products is visualized to gain a better understanding for the entire supply chain. In alignment with the recommendations of the authors, key points such as extracting actual data instead of a "should-be" state when possible, having a clear start and end for the flow and using visualization tools to describe the flow were used as extensively as possible. The start of the flow was determined to be the pick-up point of the parts from the suppliers, i.e. when the ownership of the parts was transferred. The end of the flow was determined to be the arrival to the dealers, as there is mixed ownership of dealers when it comes to Volvo or private actors and it would be too complex to track to the end consumer. However, due to difficulties in data collection in the specific national flows in Australia, data on the final distance from the RDC in Australia to the dealers was not uncovered.

According to Brewerton and Millward (2001), a case study is a description of a current event and its' consequences in a fixed time period. It has several advantages, including that it is possible to gain a deeper understanding for a particular area of interest and that this may lead to discovering information which would otherwise have been overlooked. On the other hand, the authors also describe risks with this form of research method. These include that it may be difficult to generalize findings in a way in which they are usable for other cases, that researchers may get caught focusing on details, and that it may be time-consuming to analyze the found data. In the investigation in to the selected spare parts conducted in this study, the opportunities of conducting were deemed to outweigh the risks. The risk of lacking generalization as discussed by Brewerton and Millward (2001) was mitigated through choosing a list of spare parts as opposed to single parts, in order to avoid anomalies.

Due to restrictions in data collection methods, several assumptions in regard to the mapping had to be made. These include:

- The geographical origin of the part is assumed to be the location of the supplier. In certain cases, the parts have several possible pick-up points. However, as the case study aims to create a model for impacts on supply chain performance as a result of distributed production, the exact distance between suppliers and the CDC in Gent was deemed to not of critical importance.
- The distances between the various supply chain nodes were calculated with the help of several online tools. These include:
    - Road Transport: https://www.google.se/maps
    - Air Transport: https://www.worldatlas.com/travelaids/flight_distance.htm
    - Sea Transport: https://sea-distances.org/
- The lead times extracted from the systems were the expected lead times, and hence do not include consideration of for example delays caused by breakage, lost goods or other factors.
- It is possible that the Australian RDC receive some of the selected parts from another warehouse than the CDC in Gent, in which case this could impact the calculated throughput times. This is however not deemed to be a commonly occurring event.
- When calculating the average transport reductions, an average location of the dealers in Australia was used gravitating to the majority of dealers, as it was not possible to extract data on precise demand or flows of the selected parts for the Australian market.
- The number of days taken to produce one of the selected spare parts with AM was assumed based on discussion with the external AM experts, and was calculated conservatively to keep possible improvements modest.

### *Data from Internal Systems*

For the case study, several meetings were held with employees within Volvo in order to gain an understanding of the supply chain flow of the selected spare parts to the Australian market. These employees assisted with the extraction of data from Volvo's internal systems regarding 22 selected spare part articles which were included in the case study. Furthermore the employees supported in case of questions. Employees included had positions as Refill Managers, Business Controllers, Operational Resource Planners, Dealer Inventory Managers, Advanced Analytics Manager and Head of Transport Flow Operations who work on a daily basis in the systems. The data was of a quantitative nature and was aimed to build the base of the mapping of the flows in the case study.

What data was to be collected was defined before the initiation of this collection process. Data included was: forecasts, prices, costs for transports and inventory holding, lead times for transports and inventory levels at the different inventories, amongst others. Data was collected specifically for each of the 22 spare parts articles and for each of the steps in the supply chain between suppliers and customers of Volvo. During the data collection process adaptations on what to collect were made as new information was received and as limitations became visible. Since several different systems, and several employees needed to assist with extracting data, some minor errors on the data are to expect due to differences between the systems and differences in time of the extraction of data. However, the differences in time were considered beforehand and attempts were made to limit this by extracting data during a limited period.

### *Study Visits*

Two study visits were performed during the study. The first was to an internal 3DP studio at Volvo Lundby, and the next was to an external 3DP studio at Swerea IVF. At Volvo, the aim was to gain an understanding of how AM operations could look in-house at Volvo. The external study visit, the Conference of Additive Intelligence 4.0, was hosted by the research institute Swerea IVF in co-operation with SLM Solutions, a machine and powder manufacturer. The aim of attending the conference was to gain a better understanding for current opportunities and challenges presented by varied actors and stakeholders within the AM industry. Firstly, 10 representatives from different companies presented varied AM topics based on own experiences and competencies. The conference then continued to new AM research laboratory of Swerea IVF, where a tour of the facilities and well as a poster session was attended. Further information about the study visits can be seen in Table 3

*Table 3: Study visits conducted in this study*

| Activity | Company | Date | Use of Study Visit Information in this Report |
|---|---|---|---|
| Volvo Internal 3DP Studio in Lundby, Product Development | Volvo Group | 2018-03-21 | 4.3.5 Internal AM Studio at Volvo |
| Conference of Additive Intelligence 4.0 | Swerea IVF | 2018-04-18 | 4.5.2 AM Conference at Swerea IVF |

### *Workshop*

An Additive Manufacturing workshop was already planned by Volvo and invited to this were employees which work with AM internally, and an external AM partner to Volvo. The aim of the workshop was to understand AM within Volvo, AM developments externally and to decide on how to organize the way of working with AM within Volvo. Several AM initiatives, concerns, thoughts and proposals were brought up by and presented by the different AM representatives in the organization and the external partner, one by one. This was followed by discussions. The presentations and discussions were documented and complied shortly after the workshop, in order to reduce the risks of misunderstandings and loss of information. This workshop was used for understanding the current state of AM at Volvo and the planed future development within the company. This was then used to help understand the applicability of distributed production with AM for Volvo. Further information about the workshop can be seen in Table 4.

*Table 4: Workshop attended in this study*

| Activity | Company | Date | Use of Workshop Information in this Report |
|---|---|---|---|
| **AM Workshop** | Volvo Group | 2018-02-15 | 4.4.2 AM Development and Initiatives<br>4.3.3 Internal Competency Development |

### *Internal Documentation*

Internal documentation consisting of previous business case studies and pilots on AM at Volvo was collected and reviewed to form a knowledge base regarding the current use of AM in the spare parts supply chain. Furthermore, various other information regarding Volvo Group and the spare parts supply chain was collected from internal documentation. An overview can be seen in Table 5.

*Table 5: Internal documentation used in this study*

| Source | Company | Access to view and edit information | Use of Internal Information in this Report |
|---|---|---|---|
| **Innovation and Concept TeamPlace** | Volvo Group | Employees working at the Department of Innovation and Concept at SML | 4.3.1 Service Market AM Strategy<br>4.3.2 AM Development and Initiatives<br>4.3.3 Internal Competency Development |
| **Volvo Group Intranet** | Volvo Group | All employees at Volvo Group | 4.1 Volvo Group<br>4.2 Service Market Supply Chain<br>4.2.1 Distribution Structure<br>4.2.2 Spare Parts and Order Classes |

### *Correspondence with Suppliers*

To gain an understanding for the supply market potential of distributed production, several AM service providers were contacted. The aim of the correspondence was further to gain their view of the potential challenges and opportunities with distributed production using AM, as well as their belief in the future potential in the subject. The correspondence was conducted through e-mail, as the suppliers were in geographically dispersed places. As the questions were few and straight-forward, individual interviews were not considered. 15 suppliers were contacted, of six were willing to respond to the questions. The contacted suppliers are located in Europe, Asia and the USA.

As contact was made with suppliers, they were informed of the purpose and background to the study and the cooperation with Volvo. Hence, the answers to the questions may be biased to position their company in a good light. However, the answers were still considered to be of value as they can give an indication of the direction of the supply market which Volvo is currently investigating. In addition, the contacted suppliers were foremost asked to give their view of the future of the market itself and not the capabilities of their own company. The questions sent to contacted suppliers can be seen in Appendix II.

### 3.2.2 Data Treatment and Analysis

The analysis draws use of the theoretical framework and the empirically collected data, in order to answer the RQs and hence the purpose of the study. The analysis was initiated when part of the data collection had been executed, and the continuously developed analysis then influenced how the data collection proceeded. This strategy is according to Bryman and Bell (2003) suitable for studies with qualitative elements. The data collection and analysis were hence considered as iterative processes, see Figure 15. Through this strategy, the analysis of the uncovered data could contribute to an understanding of what additional information that was necessary to collect in order to fulfill the purpose of the study. However, the quantitative data from the case study was analyzed once all the data collection of quantitative nature had been completed.

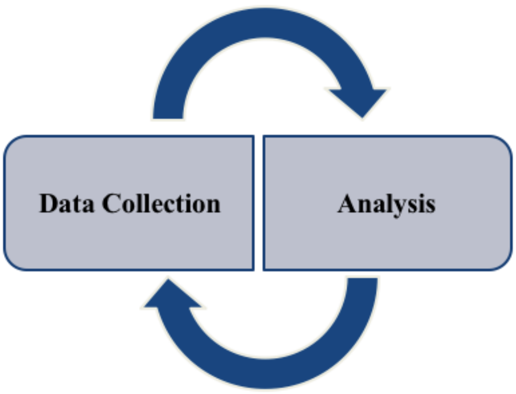


*Figure 15: Illustration of the iterative process of data collection and analysis*

In the analysis, various potential distribution production scenarios for Volvo's spare parts supply chain were generated. Based on theory in section *2.2 Distributed Production* various potential distributed production scenarios are possible and with the use of empirical information, their relevance for Volvo's spare parts supply chain was elaborated. For the case study, two potential distributed production scenarios for the 22 spare parts to the Australian market were generated in the same way. These two scenarios were mainly selected since they both would shorten the supply chain drastically in transport distance and concentrate the supply chain to Australia. The choice of scenario was considered to have an impact on opportunities and challenges with distributed production with the use of AM and is therefore presented before the analysis of potential opportunities and challenges with distributed production of spare parts at Volvo.

Theory on opportunities and challenges with distributed production guided the data collection and constituted as the foundation of the analysis of opportunities and challenges with distributed production of spare parts at Volvo. However, potential opportunities and challenges revealed from empirical findings were also decided to be included in the analysis. Potential opportunities and challenges identified from empirical findings which might not be revealed in theory did not perceive to reduce their significance, since limited theory in the area of distributed production with the use of AM was available.

Thus, six main opportunities and six main challenges with distributed production using AM were included in the analysis and they were all identified as relevant for Volvo. These opportunities and challenges were analyzed separately relatively to the context: the spare parts supply chain of Volvo. Each opportunity and challenge with distributed production using AM were contrasted with other related theory and empirical findings included in this study.

## 3.3 Quality of the Study

In order to ensure alignment between the study and the goals of Volvo, there was a close cooperation with various stakeholders within the company. These stakeholders include, but were not limited to, Volvo Supervisor and Business Analyst Emilia Gröndahl, Head of Material Planning Gerhard Kjellberg, Project Manager Marcus Wahlberg and Head of Concept and Development Christian Johansson. Regular meetings with supervisor Mats Johansson, Professor in Logistics and Supply Chain Management at Chalmers University of Technology, were also performed to confirm and anchor the progress of the study and provide guidance for the authors.

### 3.3.1 Validity and Reliability

In order to ensure credibility and dependability of the study, as discussed by Connelly (2016), varied data from multiple different sources was used as input, both in regards to the theoretical framework as well as the empirically collected data. Through using the diverse data collection methods, the analysis could be strengthened thanks to a wider and hence more solid information base. The trustworthiness of sources was evaluated continuously to ensure high quality input in to the study.

The validity of the study was further ensured through handling the collected data in a trustworthy and ethical way. The study adheres to the guidelines of ethical research methods as presented by Bryman and Bell (2003), which includes consideration of harm to participants, lack of informed consent, invasion of privacy and deception. These factors of unethical research aimed to be avoided through various measures. Firstly, all collected internal data was scrutinized and checked with appropriate company representatives to ensure that no confidential or unwanted information was published. Furthermore, both internal and external interview subjects were clearly informed of the purpose of the study and were free to turn down answering any questions they wished. In addition, interviewees were contacted after their interviews and allowed to read through the material before their answers were included in the final report. This allowed them to validate what they had said and ensure report transparency. This also adds to the conformability of the study, which is another aspect of research trustworthiness as discussed by Connelly (2016).

The trustworthiness of the interview subjects themselves has been deemed to be high. The internal interviewees were considered trustworthy as the successful completion of the project lies in the company's and its employee's interests. The correct interviewees were deemed to have been chosen, as their knowledge and expertise has been secured through several different sources within Volvo. In addition, the external interviewees were deemed trustworthy as they had no conflicting interests as a University Professor and Head of Department for a research institute, wherefore their answers were considered unbiased.

Connelly (2016) also brings up the issue of transferability regarding research trustworthiness. It is the hope of the authors that the conducted project will serve as a foundation for determining the application of distributed production for spare parts using AM. As the case study was based on a simplified version of reality with a limited number of spare parts and several assumptions, each case with different articles should also be reviewed independently as they may incur other uncertainties than the ones considered in this project. The authors hope that the findings from the study will provide guidelines in how to approach this.

# 4. Empirical Findings

This chapter will together with the theoretical framework serve as a foundation for the analysis and conclusions of the study. To answer research question one and two an understanding of the context, i.e. the company Volvo Group and its service market supply chain, is necessary. Thus, data on general company information and current distribution structure including input from personnel handling the flow of spare parts along the supply chain is presented in this chapter.

The current use of AM at Volvo is thereafter described which in the analysis will be related to the potential opportunities and challenges for distributed production with the use of AM at Volvo. Following is a description of the specific spare parts included in the case study, and their current flows, which will be used to illustrate distributed production scenarios in the analysis. Lastly, additional data on distributed production with the use of AM, from AM experts and AM suppliers, will be presented and serve as a complement to the findings from theory.

## 4.1 Volvo Group

Volvo Group is “one of the world’s leading manufacturers of trucks, buses, construction equipment and marine and industrial engines” (Volvo Group, 2018). With 95 000 employees world-wide, headquarters in Gothenburg, Sweden, and production facilities in 18 countries; the company supplies more than 190 markets with its products and services (ibid.). The vision is to “Be the most desired and successful transport solution provider in the world” (Volvo Group, 2017).

In the brand portfolio are brands which aim to address different customer and market segments of the company. Brands included in this portfolio are: Volvo (trucks, buses, construction equipment), Volvo Penta, UD, Terex Trucks, Renault Trucks, Prevost, Nova Bus and Mack. Additional brands are in the portfolio through strategic alliances and joint ventures (Volvo Group, 2017). For full brand portfolio, see Figure 16.

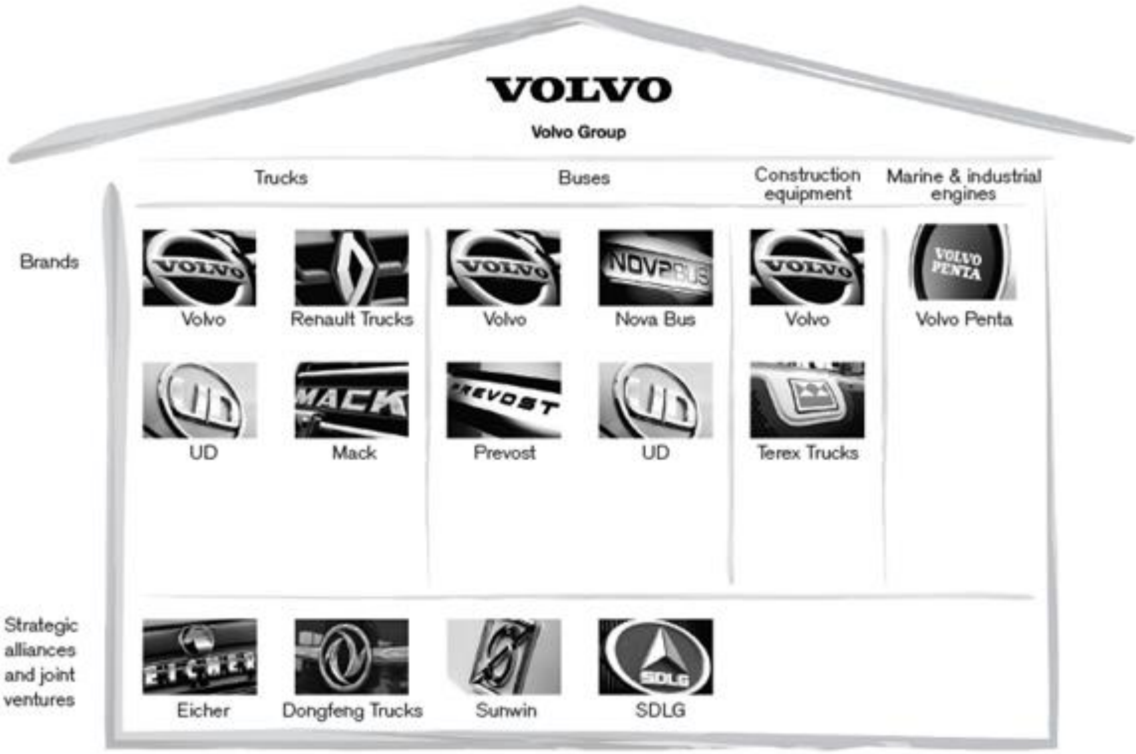


*Figure 16: Volvo Group's brand portfolio (Volvo Group Trucks Operations, 2017)*

## 4.2 Service Market Supply Chain

The end-to-end Supply Chain for Volvo Group's service market reaches from Volvo Group's suppliers to Volvo Group's dealers, see Figure 17. The strategies for this supply chain are defined by Volvo Group as follows:

- *"Deliver support for agreed end customer uptime of the Volvo Group's products.*
- *Holistic logistics approach from supplier to end customer.*
- *Take full advantage of Volvo Group's synergies.*
- *Product design for Service market.*
- *Differentiated and segmented logistics offerings to support uptime of the Volvo Group's products, to support customer expectations and brand values."(Volvo Group Trucks Operations, 2017, p.150)*

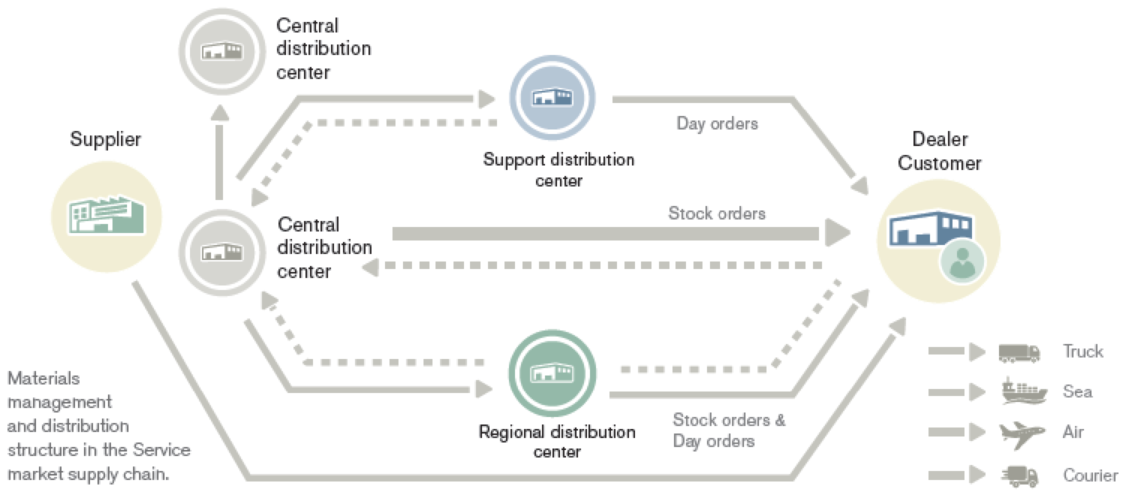


*Figure 17: End-to-end service market supply chain (Volvo Group Trucks Operations, 2017)*

### 4.2.1 Distribution Structure

Spare parts can be delivered directly from a supplier to a dealer/customer or distributed through Volvo Group's distribution centers. The strategies for distribution of spare parts are defined by Volvo Group as follows:

- *"Lean and optimized distribution network: Footprint structure and set-up of spare parts distribution centers supporting agreed uptime of the product at the lowest total supply chain cost.*
- *World class quality in deliveries to support uptime.*
- *Door-to-door transport management from distribution centers to dealers.*
- *Integrated and efficient logistics administration from order to delivery." (Volvo Group Trucks Operations, 2017, p.155)*

Three different kinds of distribution centers are used within Volvo Group for spare parts distribution: Central Distribution Centers (CDC), Regional Distribution Centers (RDC) and Support Distribution Centers (SDC) (Volvo Group Trucks Operations, 2017), see Figure 17. Locations of these distribution centers can be seen in Figure 18. The distribution centers are described in Volvo Group Trucks Operations (2017) as follows:

#### *Central Distribution Center*

Suppliers are most commonly delivering shipments to Volvo Group's CDCs. Each CDC handles the full Volvo Group assortment and stores all the different spare parts used for the brands in Volvo Group's brand portfolio. Therefore, each CDC holds approximately as many as 75.000-200.000 different parts in stock. Spare parts can be delivered from a

CDC directly to a dealer/customer, to another CDC, to a RDC or to a SDC, as shown in Figure 17.

### *Regional Distribution Center*

RDCs are smaller than the CDCs and do not hold the full Volvo Group assortment. Only a limited number of shipments from suppliers are delivered directly to a RDC. Replenishment orders are instead sent from one or a number of CDCs, as the latter deliver spare parts to secure inventory levels at the RDCs. Spare parts departing a RDC are delivered to dealers/customers, as shown in Figure 17.

### *Support Distribution Center*

SDCs are smaller distribution centers which store parts that most commonly are not in stock at nearby dealers. The SDCs also support the nearby dealers/customers with the most urgent orders. Replenishment orders are sent from one or several CDCs, as the latter deliver spare parts to secure inventory levels at the SDCs. Spare parts departing a SDC are delivered to dealers/customers, as shown in Figure 17.

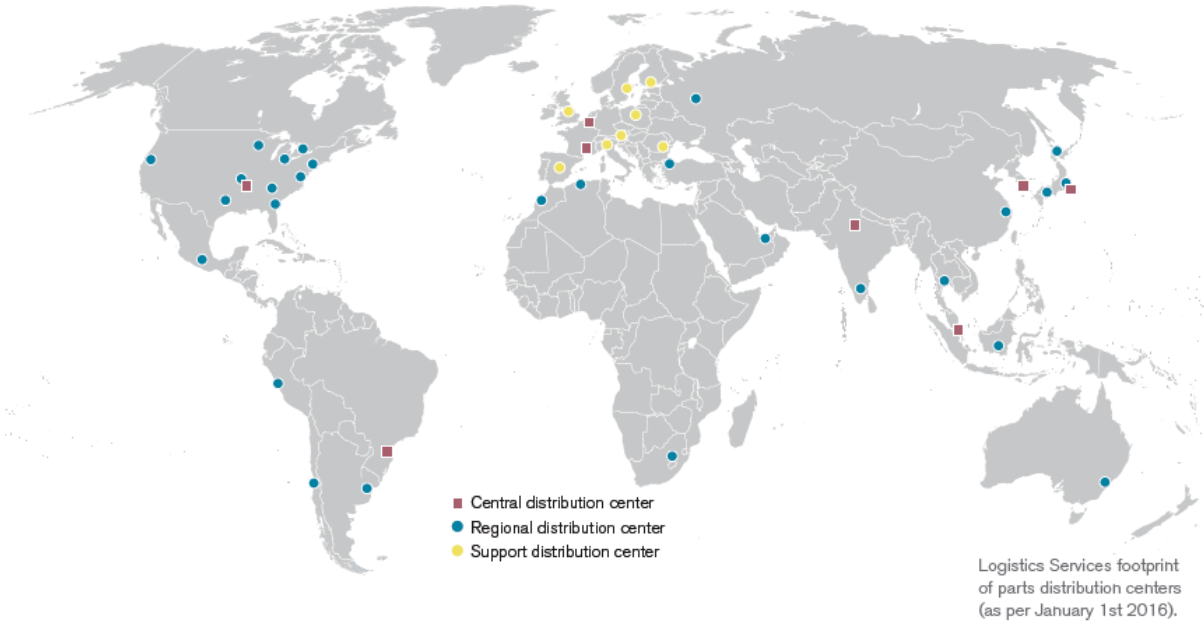


*Figure 18: Locations of distribution centers (Volvo Group Trucks Operations, 2017)*

### 4.2.2 Spare Parts and Order Classes

In the described flow of spare parts three different order types are used and handled differently. Stock orders, day orders and vehicle off road (VOR). Stock orders are used to replenish dealers stock in the most cost-efficient way, with longer lead times. VOR orders are emergency orders which are requested when a Volvo Group product has had a break down, i.e. the delivery of such order is necessary for the uptime of customers operations. Lead times for VOR orders are shorter and airfreight and courier services are used, compared to stock orders which most often use road or sea transportation. Day orders are also emergency orders of parts that dealers are not supposed to keep in stock. Day orders are delivered to dealers from RDCs or SDCs and the lead time is kept short. Overnight road transportation is most commonly used and in cases air transportation.

### 4.2.3 Material Planning Department

The service market logistics' material planning department for EU and Ghent is working with suppliers world-wide in order to secure spare parts availability in Volvo's CDCs in Ghent and Lyon. According to findings from the material planning department, a closer collaboration between purchasing and the material planners is desired. To some extent, poor sourcing has been performed which results in issues at the material planning department as a number of suppliers are performing close to zero when it comes to delivery precision. Currently, the material planning department is only invited to participate and be involved in larger sourcing projects.

The department uses several KPIs, where two of the main ones are Availability and Delivery Precision. The availability is considering all order classes and should be about 93.5 % - 96 % depending on brand. The delivery precision is expected to be 90 % for Volvo Trucks, Volvo Buses, Volvo Penta, Renault Trucks and Volvo Construction Equipment. However, the current largest challenge perceived by the material planning department relates to the many delays from suppliers, due to capacity constraints. Volvo is competing with other actors in the industry for the volume from suppliers.

The VOR orders are the most urgent backorders to customers with the highest priority. Due to the high priority, VOR orders are not handled by the material planning department, instead specific back order recovery teams are handling these orders. However, the material planning department handles day orders and stock orders, which are the order types with prior two and three.

The material planners strive for that suppliers will have only one interface, i.e. contact with only one material planner at Volvo. Larger suppliers might have two material planners to contact. Most commonly e-mailing is the tool used for communication between material planners and suppliers. In a global material planning perspective at Volvo, each material planner handles 300-500 articles. To perform the material planning processes three different data systems are used. An integrated system has been on the agenda for years, but delays have occurred. A common system is still not put in place in a global scale, but it is ongoing.

### 4.2.4 Refill Department

The refill department is part of the flow optimization and inventory planning department. The refill department is responsible for using the stock in the CDC in Ghent (for the brands Volvo Trucks, Buses and Penta) to supply other CDCs, RDCs and SDCs in the world with parts. The refill department has three main aims, which include: maintaining availability for customers, ensuring low supply chain costs and balancing tied up capital and order handling costs. This is achieved through three policy pillars which are based on what to stock, when and how much to refill, and when and which articles to return to a CDC or to scrap them.

The goal service level is between 92 and 95 %, depending on the DC. These goals are usually met, but due to capacity constrains in the automotive industry in general, there have been some availability issues recently. Preventive maintenance is also an important aspect of the work, which is why for example real versus expected lead-time, forecast quality and back order recovery (BOR) data is monitored closely. Different software systems are used in different regions, although a shift to a single system is planned and will be rolled out sequentially.

There are several factors which influence availability at RDCs. These include for example: availability at the CDCs, dealer order behavior and lead time delays caused by for example lengthy customs inspections, delays when sending or receiving at DC, or delays during the transport. Another issue is that the refill department is at times given information about promotions and expected sales peaks with too short notice, which makes availability more difficult to provide. This can hence lead to having to transport goods by air, to limit BOR.

Regarding the supply chain structure, most of the parts follow the traditional structure from CDC to RDC or SDC and then on to dealers. If there is a large order from a supplier which is destined for a specific RDC, this is routed through the CDC to ensure control. Goods are not transferred between RDCs, unless it is an emergency in the form of a VOR. Reasons for this include that there is no set-up for this type of inventory balancing when it comes to support in digital systems or transport solutions.

### 4.2.5 Advanced Analytics Department

The advanced analytics department is a new department within the flow optimization and inventory department, within service market logistics. The personnel's main competencies are within supply chain management, computer science as well as mathematics and statistics. This combination is necessary since the team handles advanced analytics within the entire service market logistics scope. Perform advanced analysis of various performances, communicate and collaborate with internal as well as external actors and visualize these findings are tasks for this department. The main focus is on intelligent processes, on those that could and need to be developed much further. Advanced analytics are performed within a wide range of areas within Volvo as for instance forecasting, planning and segmentation.

One of the areas which the personnel at the advanced analytics department have been working with includes how to do total cost calculations for storing spare parts in the company. Costs for holding the inventory, scrapping costs and costs of returns are weighted against order handling costs, rush freight costs, costs of lost sales and costs of bad will. The latter two are argued to be more difficult to estimate. They are currently included and estimated to low values, as it is argued to be more accurate than excluding them. In consideration to these costs, the lowest total cost is the main target when setting the service level.

There are several cost drivers identified which are argued to have an impact on the total costs, see Figure 19. The segment is impacting as various types of parts could be stored which have different characteristics, as for instance are: up-time critical or less critical. Up-time critical parts have higher likelihood of being shipped with air transport than less critical parts. The type of warehouse and in which country it is located, are other cost drivers defined by Volvo. Additionally, the weight of the parts, the life-cycles and the frequencies are impacting. Low volume parts have higher likelihood of being shipped with air transport and low frequency parts are often stored further away in the warehouses which increases the picking costs. The brand of the spare part is further argued to be a defined cost driver; however, this driver is commonly not considered when calculations are performed.

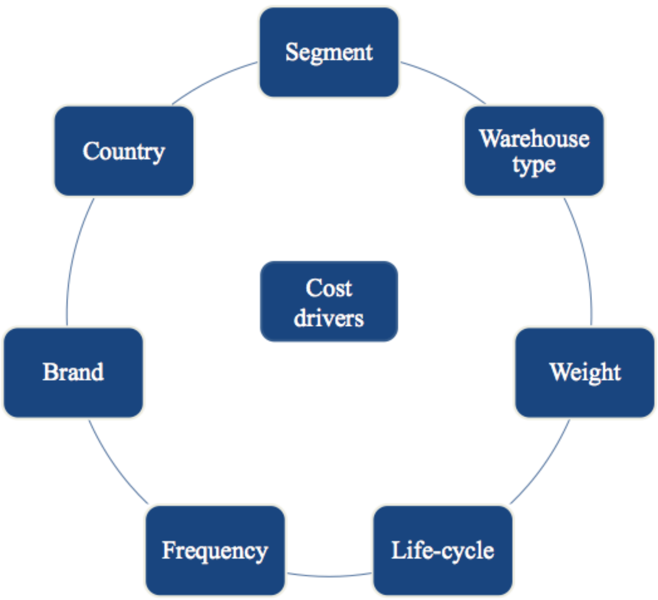


*Figure 19: Illustration of cost drivers for storing parts at Volvo*

Furthermore, the impact of cost drivers differs throughout the supply chain. When considering the different nodes of Volvo supply chain, the impact of the drivers depends on the level of decentralization. The main cost drivers for the CDCs, RDCs/SDCs and Dealers are illustrated in Figure 20.


*Figure 20: The main cost drivers at different nodes in Volvo's supply chain*

### 4.2.6 Service Center and Transport Parts Management

The team within Service Center and Transport Parts Management for EU and Ghent is the link between the dealers and the rest of Volvo regarding identified issues with products, or transportation of products, within the brands: Volvo Trucks, Volvo Penta, Volvo Buses and Renault. This entails questions related to deviations, special orders, transport questions, VOR orders, return flow etc. The personnel here function as the voice of the customers into Volvo, and the service center is being contacted when the dealer or customer is facing an issue. The communication between the service center and the dealers is mainly through a system called Argus which all dealers are connected to.

The current capacity constraints at suppliers are affecting the availability of parts and thus affect the workload at the service center. The main occupation of the service center is related to solving VOR orders; most time is spent on this. VOR orders are the second highest prioritized order type by this team and the only orders that are prioritized higher are the orders for ensuring production.

When customers are facing a VOR, this is communicated through Argus and actions are taken by the service center personnel. Several actions are available; firstly, the service center searche for the part in the European DC. Which distribution center to search in first is pre-defined and for the Swedish service center the first distribution center to search in is the SDC in Eskilstuna, thereafter the CDC in Ghent. Other actions can be to search for the part at other dealers or finding newer or older parts that could replace the missing one. The personnel can also check stock in factories. Once the dealer has notified the service center about a VOR, the service center personnel have one hour to respond to this message. However, the process of finding a part may take longer.

If the part can not be found in Europe, the Backorder teams in Lyon and Ghent take over. These teams work world-wide and can search for the missing part outside of Europe. These teams can check internal flows, kits used, alternative parts, safety stocks, prototypes, other brands sold outside Europe, stock in non-European factories, stock at non-European dealers or decide to disassembly another vehicle etc.

Once a part for a VOR order is found, this part is commonly distributed through the traditional distribution flow, i.e. most often through a CDC before delivered to a dealer. To send the part directly to the customer from where it was found has in some cases been performed but to a low level of satisfaction since parts have been found to disappear on the way. Therefore, the traditional distribution flow is used for VOR orders even if it extends the lead time. This extra handling and more costly services, such as transportation, required for VOR orders, make these orders around 75 times more expensive for Volvo than regular stock orders. The day-orders are more expensive for Volvo than stock orders, due to the extra handling and more costly services required.

This relates to one issue mentioned, which is that customers intending to place a day-order can find out that there is no stock within Volvo and therefore might try to place a VOR order instead to get higher priority on the part. The result is costly extra handling and potentially prioritization for two parts when the second one delivered might be sent back since the actual demand is already met with the first part delivered.

### 4.2.7 Back Order Recovery Department

The backorder recovery department in Eskilstuna handles Volvo Construction Equipment backorders and uses several means to solve these. Internal transfer is one of the most common means for parts that are common for several brands. It entails that a part for a brand can be transferred to another brand internally, for example from being a Volvo Trucks part transferred to be a Volvo Construction Equipment part, in order to solve a backorder.

Another simple option for the department to solve backorders is to find old parts or new parts that could replace the missing part. Repurchases from dealers or RDCs are other means, but repurchases from dealers are often a more expensive option. The department is able to reach out to production, which in most cases can help solve backorders without any interference to production. However, the BOR Department has mandate to make changes to the production if there is a very urgent backorder and no other means are available.

Volvo provides a make to order service to customers, in case a part which they require is no longer in production and in phase-out and can hence only be found at suppliers or other external sources. In this case, the customer must purchase the entire minimum order quantity even if the demand at the customer is lower than this level, in order to avoid creating large inventories for Volvo. In addition, placed orders cannot be cancelled. Customers value this service as it in many cases may be more economically beneficial to take this cost rather than lose valuable up-time of their machines.

The department perceives that the main focus is on solving backorders rather than the costs it entails. One of the main challenges mentioned is the current capacity constraints at suppliers. However, there are always some more difficult parts or problems, which affect the delivery performance and number of backorders. Some of the backorders are up to several years old, which affect customers but especially Volvo as a brand.

Therefore, AM is at this department perceived as an option in order to solve at least some of these issues within BOR, and some attempts from this department have been made in order to print spare parts internally at Volvo. A 3D-printer is located in Volvo Eskilstuna which has been used to print a plastic part and thus solved a backorder to a customer. However, the department is in its initial phase of this development towards AM.

## 4.3 AM at Volvo Group Today

This section aims to describe the current state of AM at Volvo, which in the analysis will be related to the potential opportunities and challenges with distributed production with the use of AM. Hence, the section describes areas as Volvo's strategy for AM regarding the service market, internal AM development and initiatives, internal competency development, AM and procurement as well as internal AM processes at Volvo.

### 4.3.1 Service Market AM Strategy

AM at Volvo has received increased top management focus and due to the many potential opportunities of the technology grassroot initiatives have also spread throughout the company. Volvo has been investigating how AM can improve the company's operations and have identified several opportunities and goals for the service market. These include: increasing spare part availability, minimizing stock, minimizing all-time-buy and reducing the costs associated with large minimum order quantities, increase branding flexibility and minimizing serial tooling costs. To fulfil these goals, the following Volvo Group Truck Sales Aftermarket vision for AM will be followed:

*"With the usage of Additive Manufacturing technology, our customer will see us as a leading provider of parts availability. The technology as such will help us to provide a cost-efficient aftermarket logistic set up of especially low volume parts. This leads to an increased uptime for our end users' vehicles/machines/engines"*
(Volvo Innovation and Concept TeamPlace)

While wanting to pursue up-scaling of AM to draw use of all the possible benefits, Volvo are at the same time considering the risks and challenges with the technology. They have identified several areas which are important to secure when moving forward with AM. These include quality assurance, copyright infringement and printer locations, as well as comparing in-house versus outsourced solutions.

### 4.3.2 AM Development and Initiatives

AM is something that Volvo have been working with for several years, but the focus of the scope has shifted during that period. According to Volvo's internal documentation, AM was initially used mostly for prototyping to communicate concepts and to evaluate these concepts in the user environment. Significant improvements in lead time and in production costs for these applications have been recorded. The focus then shifted towards AM printing for production fixtures, customer adaptations and for parts for special vehicles. These areas are currently using AM for daily needs. A project in designing for AM has been conducted, where potential for drastic improvements in component consolidation and weight reduction were identified.

After successful usage in the described application areas, focus is now shifting towards using AM also for production of spare parts. Several projects and pilots have been initiated in various brands and divisions within Volvo, and VORs have been solved through printing on customer demand when standard spare parts were unavailable. Future foreseen opportunities for AM include parts for regular production to reduce supply chain costs and increase customization possibilities, as well as parts designed for AM to improve functionality and decrease costs. However, when moving from perceiving AM as a new technology to implementing it in to standardized current processes, several obstacles have been encountered such as the rigidness of processes.

Due to the increased focus on the benefits of AM, multiple initiatives are currently being launched to ramp up the use of AM at Volvo. An AM workshop was held where key stakeholders from different brands and departments were present, with aim of sharing progress and knowledge about AM initiatives throughout the group. Through this workshop, a cross-functional working group was formed to support a more coordinated strategy in developing the practice of AM in the company. The current initiatives include for example establishing standardized processes for spare part selection and training engineers in designing parts for AM application.

Volvo has not yet decided on whether to have an in-house or outsourced solution for AM, it was discussed during the AM workshop that a mix between the two are currently used. Volvo has several printers in-house which are used for the range of applications as previously described, but the in-housed AM is mainly focused on prototypes. However, Volvo have connections to various AM service providers, which are able to produce parts on demand for Volvo. The strategic decision on whether to make or buy is impacted by factors such as investment requirements, the rapid development of the technology and capacity optimization, which is why Volvo currently are focusing on partnering with AM service providers, but the supply strategy is not formally conclusive.

In addition to AM's technical benefits, Volvo have identified potentials for supply chain improvements which is presented in internal documentation. Future shifts in business models is another aspect which is discussed, and projects have been launched to investigate. The main business models which are currently evaluated can be seen in Figure 21, and include in-house and outsourced solutions to AM contract manufacturers, the potential of using AM to provide a service for customers where they can place orders directly with Volvo and have AM produced spare parts shipped to them on-demand, as well as retail AM where dealers or consumers have their own printers and produce parts themselves. It is possible that the business model will change over time, and that different models can be used at the same time. There may be a difference in time frame when it comes to plastic and metal parts, due to their different characteristics and current AM conditions. Plastics have been used to a much greater extent than metals for AM, both internally and when contracting.

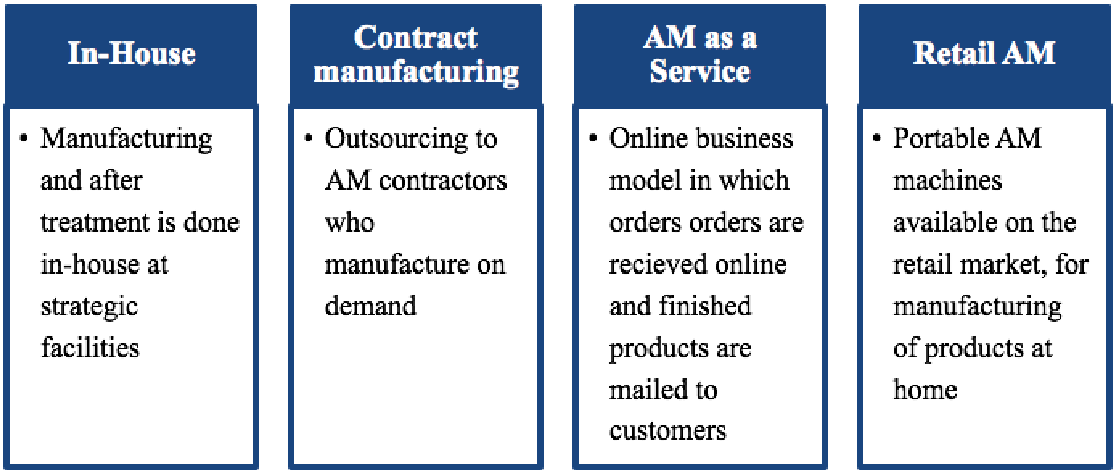


*Figure 21: Potential business models for AM sourcing, adopted from Volvo's internal documentation*

Related to the different business models are the already mentioned legal challenges with copyright infringement. A project has been conducted to investigate these challenges and recommend continued work to secure IP-rights in a potential business model shift. In this project, several software suppliers were evaluated, who provide services to enable tracking and controlling of AM through geographical distance and at external provider locations.

### 4.3.3 Internal Competency Development

Due to the various AM initiatives throughout Volvo, AM knowledge and competence is spread throughout different departments. However, due to the complexity and the many aspects of AM such as quality uncertainties, there are some challenges to large scale AM implementation. A number of areas where internal knowledge is to be improved include for example design methodologies, product and process performance, and the potential for increased design value as discussed at the AM workshop. There have also been limited continuous knowledge build up and sharing, but a cross-functional network has been set up to avoid this. In addition, there has previously been a lack of ownership for AM, which continues to be an uncertainty.

There are furthermore technical limitations to AM, such as the amount of post-treatment needed and the different material characteristics of AM printed parts in comparison to part produced through traditional manufacturing techniques. Volvo are aware of this, and as discussed during the AM workshop, quality assurance becomes critical in relation to this as it is important to consider the quality assurance process when making changes to a 3D-drawing.

Another possible barrier to AM adoption in standardized processes is the internal interdependency between actors within the company, as discussed in the AM workshop. The product development team, the purchasing department and spare parts engineering are all key actors and have a mutual dependency between them. Service market logistics are in turn dependent on the actors in order for them to meet the demands from the market. This could be a hinder in adopting for example new technologies such as AM.

There are further data reliability issues when it comes to spare part design, especially for older models, which became evident during the AM workshop as well as in internal documentation. When implementing AM at Volvo it is important to acknowledge that most of the parts are not designed with AM in mind. For example, there is limited availability of drawings which may not always identically correspond to a physical part. In addition, for parts that have a 3D drawing, may be in a CAD-format which is not supported by AM. Re-designs are therefore necessary, and although 3D-scanners can be used this requires some engineering work

### 4.3.4 AM from a Purchasing Perspective

Due to the newness of AM, and the limited previous work with the technology at Volvo, Purchasing are new to sourcing AM produced products. Knowledge gaps included limited supplier base and cost knowledge as well as limited understanding for the process itself and the segmentation of products. There are hence multiple issues for Purchasing to consider, such as applicability of current processes to AM sourcing, the possibility to use current suppliers and cost drivers of the technique. Obstacles to this included limited engineering support in process and cost analysis.

Due to demands from different areas of Volvo, purchasing began creating a supplier list for AM of spare parts and special vehicle projects on a global scale. Regular processes were followed when investigating the supplier base, including an initial segmentation, target definition and supplier identification. However, as this was a completely new project, the estimated time of completion is between 18 to 24 months instead of developing a standard sourcing strategy which takes between 8 to 10 months. This process has been disrupted because of the constant emerging of new AM techniques worth considering for use.

Special considerations such as financial and stability had to be made when creating the supplier list due to the high number of new entrants on the market. The insecurities in terms of which actors which will remain in the industry were important to consider, as there will likely be a consolidation of power in the market in the years to come. With this in mind, it was important to not only focus on the largest actors, as these may not prioritize initially low volumes and often focus on selling the actual machines instead of contracting work.

The current state of the supplier selection is that short listed possible suppliers have been sent RFQs for 45 parts considered for AM, and answers to these have been received and are under review. The suppliers are requested to both do the AM as well as the after processing in order to deliver fully finished products. With this information Purchasing aims to gain a better understanding of regional differences when it comes to capabilities, access to raw materials, machines and cost. The choice of suppliers will hence be driven by cost in relation to these aspects. These factors will be considered in determining the sourcing strategy moving forward, which will affect the long-term actions.

There are arguments both for and against a potential development of partnerships with selected AM suppliers. With a partnership, suppliers could assist in re-design of parts and greater information exchange, which may be especially interesting for spare parts. However, there are a great number of suppliers available, and the cost of switching supplier is low. In these tactical segments it may be favorable to maintain transactional relationships with suppliers due to these reasons. Despite this, it should not be disregarded that capacity restrains may occur in the future due to a supplier consolidation and less competition, but this is a future scenario issue.

Furthermore, for the Purchasing department the focus of AM sourcing is to secure a supplier base, and not to determine or plan the supply chain structure. There is a gap between purchasing and logistics when it comes to distribution strategy, which becomes more evident due to the limited matureness of the technology. The logistical costs dependent on supplier selection may therefore at times not be considered to a great extent.

### 4.3.5 Internal AM Studio at Volvo

One of Volvo's internal AM studios is in Lundby since 2003 and employs three people today. The studio has two printers, one larger and one smaller, both Selective Laser Sintering (SLS) printers. The larger printer is supplied solely with polyamide, whereas the smaller printer is supplied with polyamide, fiberglass or a polyamide-metal combination material, similar to aluminum. Switching between powder materials is a lengthy process due to the extensive cleaning which must be performed, in order to ensure purity. Hence, the larger printer is devoted to the most commonly used material.

The printers at this studio are mainly used for prototyping, and prototyping is the main focus for all of Volvo's internal AM studios. However, the personnel explain that parts to end-customers could be produced here, and a few parts have been produced here. There have been discussions at Volvo whether to print some spare parts internally, but spare part printing has not yet been performed at this studio. Overall, the personnel perceive that their studio has gained increased attention in recent years and mention that there have been discussions whether to purchase another large printer, which could cost about 10 million SEK including secondary costs, due to the increased amount of printing requests.

The process-steps for using the larger printer was described, in which the personnel working at the 3D-printing studio receive a CAD file containing a model of the product which should be printed. The personnel continue with preparations, such as digitally placing and setting the rotation of the product model in a tub model which aligns with the physical tub placed in the part chamber of the AM-printer. The personnel need to consider the size limitations for the product model to fit into the tube model, wherefore in order to produce larger parts, smaller parts are printed separately and glued together. The thickness of parts is something else to consider, as very thin parts are explained to be difficult to print. The CAD file is thereafter digitally sectioned in a layer upon layer structure. This preparation is according to the personnel performed quickly.

Once all the preparations are finished, the printing process can be initiated. A roller rolls out a layer of powder before sintering the first layer. Thereafter the powder bed is lowered 0.12 mm before the next layer of powder is rolled out. This process is repeated until all layers have been executed and the product has been sintered in the tube. The printing process typically takes around 40 hours for one tub and is performed in a temperature of circa 170 degrees Celsius. When the printing process is finished, a slow-cooling process is required which could take about three days. After the cooling process, leftover materials need to be manually removed and taken care of in order to be reused. Blasting and rinsing-off can thereafter be executed.

Overall, from starting the machine to the point of having the part ready for delivery, takes about a week if using a full-sized tub. However, by using a smaller tub in the part chamber, the time required for the printing process could be reduced, but the possible size of the part will hence be reduced. The personnel explain that the related material and labor costs for printing with a full-size tub amount to around 40 000 SEK. For a new employee to handle the full printing process in the studio, it would require around six months of training. In this includes training in preparation activities, cleaning and post processing.

The studio has received requests for larger projects which have been necessary to outsource to external actors. When such a request occurs, a prototype purchaser at Volvo is contacted by the studio and the purchaser evaluates and selects a suitable AM-supplier for the project. Such a project could take a couple of weeks.

## 4.4 Case Study of Potential Spare Parts for AM at Volvo Group

This section presents the background and various data for selected spare parts included in the case study. The selected parts for the case study are a number of parts from an ongoing AM pilot at Volvo. By mapping the current supply chain flows an understanding could be created of the various costs, transport distances and lead times which the flow incurs. This data will thereafter serve as a foundation for illustrating scenarios of distributed production in the analysis chapter.

### 4.4.1 Background of Case Study

Currently, there is an ongoing pilot to determine the potential of AM produced spare parts within Volvo Trucks. The aim of the pilot is to generate a concrete case study to gain more internal knowledge and understanding for the related impacts on processes and current ways of working. The largest identified short-term benefit is increased availability for customers. Long-term, the potential for AM are for example inventory reduction and decreased supplier dependence.

A specific market was chosen to give a clearer focus for the project, where Australia was chosen as a suitable market. Australia was chosen for the pilot due to several reasons. The Australian organization is well equipped for handling projects like the pilot due to the existence of national departments and related skills, such as Group Trucks Operations and Production. Quality control can hence more easily be performed. As a result, the Australian organization can be more agile when working with new projects.

Furthermore, the Australian market on average has an older fleet of trucks, implying that inventory and availability is more difficult to manage. This leads to the possible benefits of AM being greater. Australia is in addition of interesting geographical location as it is a significant distance away from the European CDCs and hence logistics play a greater role. The print location for the pilot is not yet set, but a local supplier is considered. Transport is currently not a major cost factor, but extensive transportation causes long lead times. In addition, long transport chains can lead to damage to and loss of goods.

The Australian organization was given a list of technical specifications and limitations from which they worked with to select suitable parts possible to produce through AM. The list was to contain only plastic parts, as the maturity of AM technology is higher for that material and it is viewed as a suitable stepping stone. The parts should additionally not be of critical nature to the truck, and preferably be an inside part where outside finish is not as important as for outside visible parts. Focus was put on selecting parts which were sold in low volumes, and the current list has parts selling roughly between 20 and 50 pieces per year worldwide. The proposed list contains around 25 spare parts.

A main focus of the pilot was to secure customer satisfaction when moving forward with AM. Great attention is put in to ensuring that the customer requirements are fulfilled, regardless of production technique. If customer needs are not met, there is a risk that customers begin sourcing their spare parts directly from external AM providers for old parts which have limited availability, as original guarantee claims no longer may be valid. Internal processes have to be adapted to cater to the new way of working which the pilot causes. Currently, the Service Market departments are not accustomed to requesting parts produced with a new production technique. Internal ownership of the AM produced parts is also a key question which must be determined.

### 4.4.2 Current Distribution of the Spare Parts in the Case Study

Out of the 25 parts in the pilot, 22 have been included in this case. The current supply chain flow for the 22 selected spare parts to Australia is illustrated in Figure 22, and the geographical flows can be seen in Figure 23 with explanation in Table 6. The parts originate from 5 different suppliers in Sweden, 1 in Norway, 2 in France, 1 in the Netherlands, 2 in Italy and 1 in Germany, see Appendix I. All parts are delivered from suppliers to the CDC in Gent, Belgium before being transported to the RDC in Sydney, Australia. The RDC supports 97 dealers in the Australian market. The parts are currently delivered by different transport methods, as illustrated in Figure 23.


*Figure 22: Illustration of the current flow of the selected spare parts in Volvo's supply chain*

*Figure 23: Illustration of the geographical location of supply chain nodes and transport routes*

*Table 6: Explanation of the symbols used in Figure 23*

| Symbol | Explanation |
|---|---|
| ● | Current Suppliers |
| ▲ | CDC Gent |
| → | Road Transport |
| → | Sea Transport |
| - - -> | Air Transport |
| ▲ | RDC Australia |
| ○ | Dealers |

The throughput time for the parts through the flow from the supplier to the dealers can be viewed in Table 7. The lead times at the suppliers vary between 7-35 days for parts that are still offered. Part E is superseded without replacement and therefore the lead time at the supplier is set to zero, wherefore this product is not included in calculations of lead times performed in chapter *5. Analysis and Results.* The transport lead times for each article between the supply chain nodes are further defined and presented. Parts from the CDC to the RDC can be transported either by air or sea, wherefore different transport lead times could be considered. The throughput times for each article at the CDC and RDC have been calculated, for more information about the calculations; see section *3.2.1 Data Collection* and Appendix I.

*Table 7: Throughput times for each article from suppliers to dealers in Australia in days*

| Part | LT at Supplier | LT from Supplier to CDC | TT at CDC | LT from CDC to RDC Air | LT from CDC to RDC Sea | TT at RDC | LT from RDC to Dealer | Total TT Air | Total TT Sea |
|---|---|---|---|---|---|---|---|---|---|
| **A** | 14 | 14 | 607 | 14 | 63 | 537 | * | **1185** | **1234** |
| **B** | 28 | 28 | 320 | 14 | 63 | 1227 | * | **1617** | **1666** |
| **C** | 14 | 14 | 104 | 14 | 63 | 255 | * | **400** | **449** |
| **D** | 21 | 21 | 2636 | 14 | 63 | - | * | **-** | **-** |
| **E** | 0 | 28 | - | 14 | 63 | 0 | * | **-** | **-** |
| **F** | 28 | 28 | 195 | 14 | 63 | 782 | * | **1048** | **1097** |
| **G** | 28 | 49 | 1318 | 14 | 63 | 1141 | * | **2550** | **2599** |
| **H** | 28 | 14 | 220 | 14 | 63 | 13 | * | **289** | **338** |
| **I** | 28 | 14 | 227 | 14 | 63 | 160 | * | **443** | **492** |
| **J** | 7 | 35 | 8427 | 14 | 63 | 8670 | * | **17153** | **17202** |
| **K** | 35 | 7 | 165 | 14 | 63 | 0 | * | **221** | **270** |
| **L** | 21 | 14 | 91 | 14 | 63 | 104 | * | **244** | **293** |
| **M** | 21 | 14 | 74 | 14 | 63 | 67 | * | **189** | **238** |
| **N** | 14 | 28 | 37 | 14 | 63 | 128 | * | **221** | **270** |
| **O** | 14 | 28 | 26 | 14 | 63 | 149 | * | **231** | **280** |
| **P** | 21 | 14 | 29 | 14 | 63 | 41 | * | **119** | **168** |
| **Q** | 14 | 14 | 2 | 14 | 63 | 826 | * | **870** | **919** |
| **R** | 21 | 28 | 33 | 14 | 63 | 41 | * | **137** | **186** |
| **S** | 35 | 7 | 52 | 14 | 63 | 190 | * | **298** | **347** |
| **T** | 35 | 7 | 56 | 14 | 63 | 194 | * | **306** | **355** |
| **U** | 35 | 7 | 57 | 14 | 63 | 342 | * | **455** | **504** |
| **V** | 35 | 7 | 19 | 14 | 63 | 406 | * | **481** | **530** |

* = Missing information
TT = Throughput time
LT = Lead time

## 4.5 External Development of AM and Distributed Production

This section contains data on AM from an external perspective, in order to gain an understanding of the opportunities and challenges which AM and distributed production may entail. Hence, this data will be used as a complement to the theory which covers the same areas. The section includes data provided from an AM expert at Chalmers University of Technology, data collected from several stakeholders attending an AM conference at Swerea IVF as well as data from an AM expert at Swerea IVF. Finally, the market potential for distributed production with the use of AM from the perspective of AM service providers rounds off this section.

### 4.5.1 The View of AM and Distributed Production of an AM Expert at Chalmers

The AM Expert at Chalmers is a Professor in Surface Engineering and runs the AM competence center in Sweden for AM. The competence center focuses on metal AM but has polymer capacity as well. Together with his team, the expert holds dedicated courses in AM which are increasing in popularity. A strong focus was put on AM a few years ago, and the center now has the most AM projects in the entire country. The timing of the initialization of the competence center was important, as 10 years ago it would have been too early, and in 10 years it would be too late.

The AM expert argues that it is almost always difficult to know and foresee when the time is right when it comes to new technologies. Initially, it is difficult to see the difference between disruptive and linear innovations. People are often mistaken until the disruptive innovation begins to gain momentum and are then taken by surprise. This can be seen in various technology areas throughout history. The AM expert explains that Sweden currently produces about 25 % of the metal powder in the world. Very little is used for AM, but the technology base and knowledge are there. If AM continues to grow, Sweden may hence have a role to play, also due to its industrial structure.

The AM expert does not believe that AM will replace traditional manufacturing. AM should be considered in a context other than traditional component thinking, not as just another manufacturing technique. It is hence of significance to consider the entire supply chain and new business models. Actors who are far along in AM implementation, such as in the aerospace and medical sectors, consider AM more in terms of establishing new value chains or in new contexts. However, those industries use expensive materials for their components and weight of them is critical, making AM a profitable scenario early on due to its possibility to reduce component weight. The AM expert explains that in order to really benefit from AM, companies should consider new product possibilities, such as designing for AM with light weight design and component consolidation. It is worth considering what the value offering and the business models of the future will be, and the possible shift from selling products to selling services which many industries are undergoing.

#### *AM Adoption and Implementation*

The AM expert argues that companies must realize their own degree of maturity within AM, and if it is too low they must improve their level of knowledge. If it is low, one has to start with a learning process, initiating projects to increase knowledge and maturity. Companies must then consider questions such as choice of AM technology, what level of flexibility they require and how many different materials are needed. In addition, logistical questions are at least as important as the technological aspects of AM. It requires speed to accomplish significant goals, and logistics play a central role in this. Building a small detail with powder-bed technology takes around one day, and to then deliver products to customers in a close time frame becomes of outmost significance. As another example, metal powder for printing is needs to be available within a certain amount of time. The winner of the industry may hence be the sharp logistics company who is efficient in getting things from A to B on time.

The AM expert continues to explain that which actor in the chain should do what is important to consider, and what should be done internally or outsourced, or if a Joint Venture should be formed. This could be done with either an AM service provider for part printing, or with a traditional supplier. Traditional suppliers have the post processing equipment and are skilled in surface finishing. On the other hand, AM service providers have skills in AM, including the entire design knowledge. The choice is a strategic question, and companies must decide who owns which processes. As a company, it is important to consider the entire AM-eco system. Besides printer location you need machines, powder stock, expertise and quality assurance in all of this combined. Secure digital transfer of files is also of outmost importance.

### *AM for Spare Parts*

AM for spare part production is according to the AM expert interesting as companies can essentially provide any spare parts for an unlimited time without stock, although it may be costly. As an automotive customer, you come to expect availability directly when it is needed. In order to identify the low hanging fruits in the aftermarket, parts could be segmented by volumes and other product characteristics to know where to start. For spare parts, with significant variation, a hybrid AM machine may be worth considering. The machine combines additive and subtractive machining, enabling it to complete final parts through setting the surface finish in a single machine and avoiding other post-treatment processes. Companies could consider modular thinking, for example in order to make a family of spare parts, build a special part and then process material to create different variants. Different technology choices have different possibilities and limitations.

### *Quality Compliance*

Regarding quality compliance, control of all involved processes is important. When adopting AM for functional parts, the AM expert believes it is best to focus on non-critical parts with relatively low requirement specification, to test the system and ensure that quality can be maintained. In addition, the AM Expert believes that it may be difficult to spread out production in too many locations and still ensure quality standards. Hence, the AM Expert currently does not believe in distributed production, as the AM Expert argues that the whole AM-system has to be quality certified. This will become very complex, as it would include the machine, the material flow, the involved operators and the information flow for almost every part.

According to the AM expert, if companies are to ensure quality, they have to decide on a specific type of machine, and perhaps partner with another actor on a specific site. As the technology is today, it is not possible to print the same part in two different machines and expect identical outcomes. This is because there is a black-box in how to trouble-shoot printing parameters in AM machines. In case companies choose to partner with a service provider who has global printing facilities and they are asked to print at the closest possible location, quality compliance can be demanded from them.

### *AM Technology Development*

Regarding AM technology development, the AM expert argues that machines will become relatively cheaper but not at a fast pace. The same can be said for print speed, which will improve but not quickly. There are specific machines for specific materials, and to change material in one machine requires extensive cleaning and controlling. AM investments should therefore be considered in terms of costs and utilization, as any other investment, where technical limitations are included. It should be considered that it is not as easy as feeding a machine a CAD-drawing. Expert knowledge is needed to some extent, to adjust for the application software, set the orientation, correct mathematical errors, and then prepare for printing. Additionally, the print program does not always match one to one against the CAD file which means you need knowledge of the product.

Regarding supply chain speed, the AM expert highlights the importance of being well prepared for AM to be successfully implemented. In the example of spare parts, the AM Expert argues that the whole process must be prepared, part files must be ready and the process quality assured, from file to pushing of the print button. Otherwise, this will cause a bottleneck. Securing the entire process requires expert knowledge. Companies should aim to automate as many of these processes as possible and ensure efficient digital flows.

### 4.5.2 AM Conference at Swerea IVF

During an AM conference, hosted by Swerea IVF and SLM Solutions, attending AM actors shared knowledge and experiences within metal AM and general AM. Swerea IVF is a research institute who cooperates closely with for example the manufacturing industry both nationally and internationally, and SLM Solutions is an AM machine manufacturer who focuses on selective laser melting machines. The insights were valuable since both opportunities and challenges with AM were presented, along with case studies.

### *Swerea IVF*

During the conference, a Swerea IVF representative presented how it is important that the whole AM supply chain is considered when evaluating and adopting AM. It was described that Swerea IVF covers five main areas related to the AM supply chain as the research institute is active within powder management, design for AM, manufacturing, post processing and quality assurance. It was described that several post processes are available, some of these include: blasting peening, heat treatments etc. In addition, a variety of quality assurance services such as 3D-scanning and stress analysis amongst others are available.

Another Swerea IVF representative more deeply presented insights related to AM powder. The representative explained that there are various kinds of powders available on the market which could be used for AM, however these powders have different characteristics including different powder sizes, shapes and distribution which impacts the powder flowability. Furthermore, since the printers of the various brands are not identical, as for instance various powder spreading techniques are used, not all powders could be sufficiently used in all machines on the market. The various powders are also argued to differ when it comes to fatigue properties. Therefore, Swerea IVF measures the powder before adding it in to any machine, to understand its suitability.

### *SLM Solutions*

One SLM Solutions representative brought up how AM is used within the medical industry. AM has shown to bring advantages there such as enabling mass customization and manufacturing of parts with complex geometrics. Other advantages mentioned related to reduction of costs, integration of functions and increased productivity. The representative furthermore explained that AM in some cases is used for serial production within this industry.

SLM Solutions provides several AM machines. The machines come in different sizes, with various effects, with various laser configurations etc. However, the representative clarifies the importance of safety for the workers, wherefore all machines are built in order to limit the direct contact the worker will have with the powder when preparing the machine. It was underlined that it is unclear how different powders impact on human health. Quality assurance was another area which was emphasized by the company. SLM Solutions uses several different means for quality assurance including using layer control systems, sensor techniques and laser power monitoring, amongst others. Another representative at SLM Solutions, in the area of additive intelligence, presented a platform independent software solution design to support AM. The software included four parts: additive designer, additive palletizing, additive quality and additive plant, all used to support the AM process.

Another SLM Solutions representative focused on the 3DP serial production in the automotive industry. The representative emphasized that we need the whole supply chain to make things happen. However, it is argued by the representative that AM should not be viewed to replace existing manufacturing processes, rather to be used for new parts. Customers are demanding quality, productivity and case studies. In the area of quality, different tools could be used for assurance and it is important to question how to monitor and control as you want to ensure a robust process, not only perform a control at the end. In the area of productivity, the representative argues that it is within the low volume segment which the opportunities are. Several case studies were brought forward, including the first 3D printed super car “Blade”.

### *Volvo Group*

Two Volvo Group representatives presented AM from Volvo Group's point of view. One of the representatives works with the development of AM within Volvo Group and represents Volvo Group Trucks Technology (GTT). This representative defined prototyping, serial and aftermarket parts (low volume parts), tooling and new businesses to be areas of opportunities for AM in the company. It was stated that Volvo Group offers diverse product offerings, thus has many product variants with low frequencies. There are further many small plastic parts. The main AM targets are on-demand passive parts, on-demand BO/VOR and on-demand of phase out parts.

However, there are several decisions left to make for Volvo Group, one of these relates to the potentials of producing AM parts in-house versus an outsourced solution. In-house specialized hubs and Volvo owned print hubs are potential solutions to evaluate as well as external AM service providers and how current suppliers could be used. Furthermore, it was mentioned that Volvo Group is lacking a strict governance structure for AM and the representative is not aware of all AM initiatives which are taking place within the company. The representative further argues that: “you have to do trial and error, it is OK to fail”.

The representative defines one of the main AM challenges for Volvo Group to be the ensuring of skills sets and sufficient processes. Engineers need to be educated and the AM knowledge must increase. The other main challenge at Volvo was explained to be quality assurance, as the company lacks a sufficient quality assurance process for low volume products. The representative brought up several other common AM challenges in the industry, such as: powder supply, plastic parts lifetime, metal surface properties and fatigue, dimensions restrictions, finishes and reproducibility. The other Volvo Group representative, who was representing Volvo Penta, refers to AM as not solely being about the technology, but a journey of culture.

### 4.5.3 The View of AM and Distributed Production of the Head of the AM Group at Swerea IVF

The Head of the AM Group at Swerea IVF has been working with AM for about two years and he has also a background from traditional manufacturing processes, like machining, from the bearing industry. Aside from working with machining, he has been working as a researcher within material science. The interviewee sees AM as a complement to traditional manufacturing methods and argues that many companies in a wide range of industries can benefit from adopting the technology.

The interviewee believes that the challenges associated with AM are similar to those of any other manufacturing technique once they were introduced to the industry for the first time. Every supply chain needs to be qualified and certified prior to being implemented in the industry on a broader sense. AM in itself should not cause a large difference in how this quality assurance is performed. However, a short-term problem may be to secure supplier process robustness, as there are still deviations when it comes to the output. For example, using identical powder material and CAD-file in three different AM machines, we will experience three different results with respect to mechanical properties, surface finish, distortions, etc. Even though machines from the same manufacturer are used, there are still some deviations. Standardization of the AM industry will happen, but it will take time due to the newness of the technology and the many stakeholders spread over the world which are involved. This includes in all areas of AM, including powder and machine manufacturers. Everything comes back to securing the technical processes, and it is also uncertain how quickly the technology will improve.

Something unique for AM could be AM machines which works as dispensers, where end customers could go to have their products printed on demand. This could be a major disruption in how companies do business. However, it is not a simple implementation, it would require that the part does not need any after-processing or that the machine could perform these operations itself. There are developments in hybridization of AM machines, but still there are much work left before such machines are used on a broader sense.

The idea of AM and distributed production enabling virtual inventory is a major opportunity, but due to the lack of process robustness, the market is not mature for this yet on a larger scale. Currently, this is realistic for certain limited products where the entire process is secured and quality assured. This includes specifying select parts with specific drawing, powder, AM machine and after-processing as well as the AM environment. Repeatedly changing drawings to customize parts is therefore difficult, as each change requires extensive work. However, technology will continue to develop which will improve these possibilities. Another major opportunity of AM is to enable up-time in industries which are heavily dependent on this, such as in the process, medical and the aerospace industry.

Regarding the price-development of AM machines, it was stated that AM machines for metal printing will most likely continue to be relatively expensive, ranging roughly between 5 and 15 MSEK. Polymer AM machines are significantly cheaper, where the cost is approximately 50-100 TSEK for smaller machines, and up to 1 MSEK for industrial systems. There is hence a difference in time-horizon when it comes to polymers and metals, where the former has come further material wise. Metal AM machine manufacturers invest heavily in R&D to improve printers, which means that the price for them will continue to be relatively high in the near future. The investment in R&D is spread throughout the AM network and includes for example material providers. Eventually however, the price will fall, but the time horizon is uncertain.

According to the Head of the AM Group at Swerea IVF, there is a need for education to diffuse the adoption of AM in to industry and society. Firstly, there is a need for academia to educate students in AM. Secondly, engineers in company need to be trained in the technical limitations and opportunities with AM to draw use of the possibly benefits such as part consolidation and weight reduction. Designing for AM will hence be important for companies to consider.

Regarding distributed production, the interviewee believes that this is a natural development of the AM industry. Suppliers will most likely specialize to cater to certain industries, due to their different demands and certification demands. This is important in order to become good at manufacturing specific parts. AM will hence develop in the same direction as any other manufacturing technique.

### 4.5.4 The view of AM and Distributed Production of AM Service Providers

AM service providers are part of Volvo's AM network, and can potentially become more important actors as Volvo continue their AM adoption. These actors possess knowledge of AM and distributed production wherefore their input have been collected and will serve as a supply side point of view. Thus, this section includes a compilation of the AM service providers' current market presence, their quality assurance processes as well as their current and future perspective on AM and distributed production.

#### *Current Locations and Volumes*

If distributed production of spare parts is to be adopted, it will entail low volumes sourced from geographically dispersed sites who will provide parts for certain markets. Hence, it is significant to understand in how many locations and what the typically produced volumes currently are at suppliers. A compilation of the contacted suppliers and their coverage can be seen in Table 8.

*Table 8: Supplier locations and typical volumes*

| Supplier | AM Locations | Typical volumes |
|---|---|---|
| **A** | 1 Site | 1 – 1000+ |
| **B** | 2 US + 2 Germany | 1 – 1000+ |
| **C** | 7 US + 1 Brazil | 1 – 1000+ |
| **D** | 1 US + National Partner Network | <10 – 100+ |
| **E** | 3 US Locations | 1 – 50+ |
| **F** | 13 Sites | Varies Greatly |

When it comes to producing small volumes, and packing and shipping these, most of the suppliers state that this is something they are accustomed to. Standard 3PLs are used, and on request the companies can use customer specific packing material. In regard to different AM technologies and materials, most suppliers state that there is some specialization in these aspects at the different sites. Hence, not all manufacturing sites employ all techniques in the company catalogue for most of the questioned suppliers.

### *Quality Assurance Processes*

In regard to quality, the majority of the suppliers refer to ISO-certifications of their processes. An array of quality inspection is performed, including visual inspection and spot-checks to validate machine accuracy. All suppliers state that they either send quality assurance reports of process data available on a regular basis or by request. According to Supplier B, there are different demands in how the quality assurance process is performed and reported depending on the market. For example, aerospace and defense industry demands differ from automotive.

### *Current Level of Distributed Production*

Most suppliers which have more than one printing facility state that they currently manufacture the same parts in different geographical locations, closest to the demand. However, several suppliers state that it is not common for low volume parts. When ensuring quality across geographies, several suppliers state that the same equipment, inspection capabilities and processes are to be used. Supplier F underlines that data regulation is an important part in this, and that contracts need to be signed in order to send data to different locations.

Moreover, when it comes to quality and distributed production, the suppliers emphasize that there are certain required measures needed to ensure compliance. According to Supplier A, distributed production is possible as long as you set the powder characteristics, the machine model and the build parameters, it is possible to certify the reproducibility of a process. Supplier B explains that they ensure replicability through identical machines and settings with the same build protocol.

Another important aspect to consider in distributed production, as highlighted by Supplier B and Supplier C, are the operational factors which have a large impact on part replicability. Supplier B state that the same part can be printed on an identical machine in different locations but with different outcomes. The individual operators can potentially set up the build using different orientations, which affects part performance. Other considerations are how machines are maintained and calibrated, as there could be slight variations. A customer must hence determine a proven build strategy, and specify for example material orientation, layer thickness and dimensional requirements. Supplier C states that to circumvent problems in differences that may arise, the same project engineer handles communication with the manufacturing team across the different facilities. Through this, the engineer is familiar with the parts and processes involved. Supplier E argues that 3D Printers do not always produce the same design the same way more than once.

### *The Future of Distributed Production and AM*

Most asked suppliers state that they see a more decentralized AM market in the future, although several suppliers believe it will be centralized on continent level. According to Suppliers A, the main drivers for this will be maintaining appropriate lead times while still reducing the fixed cost induced by building AM factories.

Supplier E on the other hand believes in a centralized future of AM, due to the possibility to ensure control and remain responsive if repairs are needed. Further argued is that specialization in techniques can be an obstacle to distributed production. Supplier F argues along similar lines and believes that there will be both dispersed and centralized form of AM in the future. For consumption level AM products, with the popularity of desktop 3D printers, many families, schools and companies will have their own. It will hence be more dispersed. For the industrial and professional 3D products, it will be more centralized since this is more economically viable.

However, according to Supplier B, the key benefit of AM is decentralized manufacturing, where the 3D data will travel but not the parts. Supplier B believes that parts will be made on demand at the required location. The main drivers are argued to be customer demand and logistics costs, tariffs and timing. Supplier D explains that AM machines continue to be improved, the entry barriers in to the market will be lowered leading to distributed sites offering AM. Further drivers for this will include AM cost decreases and acceptance by industry leaders.

Supplier C predicts a distributed future of AM, to cut logistics costs and to be able to serve multiple time zones. It is further argued that having representatives and manufacturing locations near the end user allows for access to AM during regular working hours. As fuel prices and logistics become more expensive, having a manufacturing location near the end-user may be beneficial. Cost and benefits of not holding inventory and an improved the customer experience will also be main drivers. According to Suppliers A, the main drivers for the up-scaling distributed production will be when OEMs request AM produced parts for serial production. As stated by Supplier D, AM will continue to grow in diversity over the next 20 years, but continued growth will be determined by new technology development.

# 5. Analysis and Results

The theoretical framework and the empirical findings indicate that there are several opportunities and challenges related to distributed production with the use of AM. In this chapter, the findings will be analyzed in order to draw conclusions and thus answer the research questions of the study.

In order to understand different scenarios of distributed production with the use of AM which could be applicable for Volvo's service market, the chapter beings with analyzing various possible supply chain structures. These possible supply chain structures will be generated based on findings from the theoretical framework and empirical information, with consideration to the specific company Volvo. Thereafter the chapter, with the use of the various supply chain structures, will analyze the opportunities with distributed production with the use of AM (RQ1). Following is the analysis of the challenges and risks with distributed production with the use of AM (RQ2). The opportunities and challenges with distributed production using AM presented in the theoretical framework have been compared and contrasted with the empirical findings, and applied to Volvo's company specific service market supply chain characteristics. From this, six opportunities and six challenges and risks have been identified. The analysis will explore the potential effects of these opportunities and challenges for Volvo's service market, and in certain cases consider how these could potentially be managed by Volvo. The analysis will not recommend a strategy for Volvo to move forward with distributed production using AM, but instead aid in fulfilling the purpose of contributing to the understanding of the effects of distributed production using AM for Volvo's service market.

## 5.1 Scenarios of Distributed Production

As presented by Srai et al., (2016), there is a relation between AM and distributed production as the former can be considered as an enabler of the latter. In order to gain an understanding of the opportunities and challenges related to the combination of the manufacturing technique and the supply chain structure in the automotive service industry, it is important to consider the different levels of distributed production which are possible for Volvo.

As presented by Matt et al., (2014) there are eight different levels of distributed production relating to required flexibility, location and aim as presented in section *2.2.1 Characteristics and Drivers for Distributed Production*. When considering AM as an enabling factor for distributed production, these levels can be grouped in to three possible categories which could be evaluated for Volvos for spare part supply chain. These are hence closely interlinked with the various business models that AM may enable, which have been identified by Volvo and are presented in section *4.3.2 AM Development and Initiatives.*

The first category includes types one to four as presented by Matt et al., (2014), which are in-house AM solutions. Here, more or less flexible production units would be spread throughout the world to supply markets which Volvo is active in. This could be done at various levels, for example in proximity to CDCs, RDCs or Dealers. In regards to the decision on which level to produce, it would result in various effect for the cost drivers as argued in section *4.2.5 Advanced Analytics Department,* and the drivers of supply chain performance discussed by Chopra and Meindl (2016). If this category would be pursued, it would also change the business structure of Volvo as a company, as their position in the supply chain would steer towards part production cutting out suppliers.

The second category of types of distributed production according to Matt et al. (2014) which could also be applicable to Volvo are types five and seven, an outsourced solution where more or less exclusive suppliers are used to print on request from Volvo. In theory, these suppliers could also be located at different geographical locations in proximity to CDCs, RDCs or Dealers, or asked to ship directly to any one of these. The choice of the level of distributed production is however heavily reliant on the location of existing suppliers and of AM service providers. Both these groups of actors are possible collaborators for Volvo in terms of AM, as argued by a Volvo representative in section *4.5.2 AM Conference at Swerea IVF* and by the AM expert at Chalmers, but will incur different challenges.

The final category of distributed production for AM consists of type six and eight as argued by Matt et al., (2014), and contains an increasing reliance on external actors. Here, the location of production is not set, and have the highest level of flexibility. The two potential business models considered by Volvo which relates to this includes AM as a service, which could in theory be either in-house or outsourced, and Retail AM, where consumption and production are intertwined, as argued by Kohtala (2015).

All three categories propose different supply chain structures with production closer to the end customer. As described in section *4.2 Volvo Group Service Market Supply Chain,* spare parts in Volvo's current spare part supply chain are often distributed through one or several CDCs and RDCs before being delivered to a dealer. However, various scenarios of distributed production could shorten this supply chain and three of these potential scenarios are illustrated in Figure 24. The first scenario could be considered as a more distributed solution for parts which currently are distributed through several CDCs or RDCs. Scenario two eliminates distribution through a CDC and scenario three eliminates distribution through DCs at all.

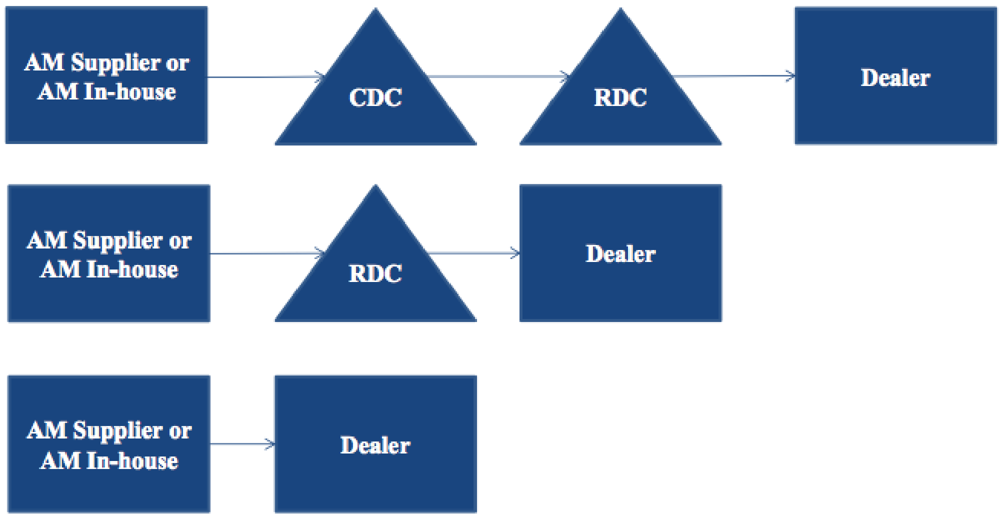


*Figure 24: Illustration of three possible scenarios of distributed production with AM at Volvo Group*

### 5.1.1 Distributed Production Scenarios for Case Study

Mapping the current supply chain of the spare parts could result in an increased understanding of the various costs, transport distances and lead times which the current flow incurs. This is in line with the argumentation by Jonsson and Mattsson (2009), who state that performance measurement is a key aspect when considering a decentralized organizational logistical structure. The case study will serve as an illustrative example of the difference between the current supply chain for the current and future scenarios, for the selected spare parts.

The selected parts for the case study are currently produced in Europe and delivered to customers in Australia. There are several potential scenarios of distributed production which could shorten the supply chain, by eliminating nodes. The current supply chain and two potential alternative scenarios are illustrated in Figure 25. These two specific potential scenarios have been chosen to be investigated due to the long distance between Ghent and Sydney, thus both scenarios reduce the transport distance significantly and concentrate the supply chain to Australia and illustrate the possibilities of distributed production with AM. Other potential scenarios could for example include printing directly at dealers. However, this is not deemed to be a viable alternative in the foreseeable future due to the challenges presented in section *5.3 Challenges with Distributed Production of Spare Parts using AM.*

The first potential scenario is using an AM supplier or an AM In-house printing solution in Australia, after which the parts are distributed through the RDC in Sydney before delivery to dealers. The second potential scenario also uses an AM supplier or In-house solution for printing in Australia, but the spare parts are delivered directly to dealers. Whether this printing is done in-house by Volvo at the warehouse or at an AM service provider is not significantly important for the case, but if a supplier is used, it is assumed to be located relatively close to the RDC.

The decision of which future scenario to use may be dependent on the aim of the part and several other factors. Reasons for shipping parts to the RDC may be that they are made to stock, and hence will be kept as inventory there. Another reason could be that the parts need to be packed in to kits or repackaged in other ways. The other possibility is that the AM manufacturer ships directly to the dealer which has a customer that requests the part. This decision will hence depend on the logistical implications, a trade-off between lead time and inventory levels and the urgency of the part. This is related to the cost drivers of the part, as described in section *4.2.5 Advanced Analytics Department*. Each part will hence have a separate business case determining whether distributed production is viable and beneficial, based on these drives and the opportunities and challenges discussed in the following sections.

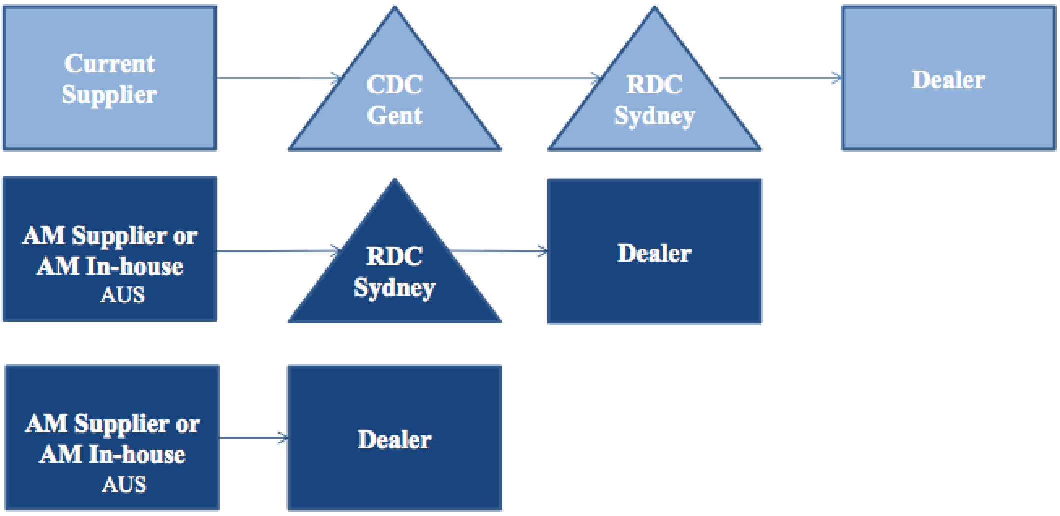


*Figure 25: The current and possible future supply chain flows for selected spare parts*

In the potential future scenarios, the spare parts supply chain is limited to the Australian region. The geographical comparison between future scenarios and the current spare part supply chain is illustrated in Figure 26 and Figure 27.

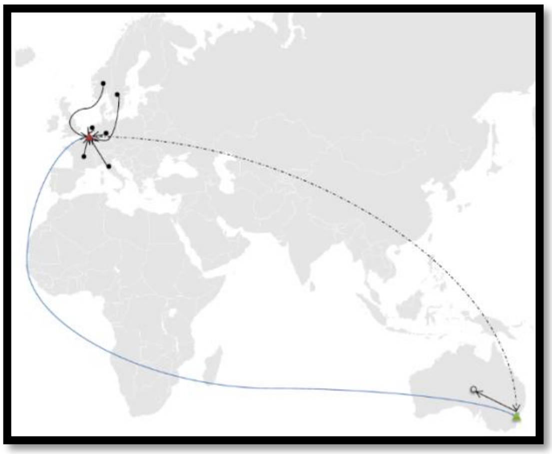

*Figure 26 & Figure 27: Illustrate the current and the potential scenarios of the geographical flows. The end point of the flow illustrates all dealers in the Australian market*

## 5.2 Opportunities with Distributed Production of Spare Parts using AM

As described by Oettmeier and Hofmann (2016), there are for example several opportunities with new product design for AM, and as argued by Roger et al. (2016) AM can be beneficial in low-volume production and in customized products. There are also arguments for distributed production, as Khajavi et al. (2014) and Durão et al. (2017) argue that it can lead to significant supply chain improvements. The question is how these opportunities apply to the specific automotive spare part industry of Volvo, which according to the reasoning by de Souza et al. (2011) would be characterized by long-life cycles and according to Li et al. (2017) sporadic demand.

When a distributed production set-up for the spare part supply chain using AM is considered by Volvo, the associated opportunities are important to consider, in order to determining whether they are sufficient for the business case and if they align with the overall company strategy. Six potential opportunities with distributed production were described in section *2.2.2 Potential Opportunities with Distributed Production*, and findings from the empirical data aligned with several of these, wherefore these six opportunities will be included in the analysis and analyzed related to Volvo's spare parts supply chain. A compilation of the opportunities included can be seen in Figure 28. A summary of the opportunities and their respective key points will round off the section.

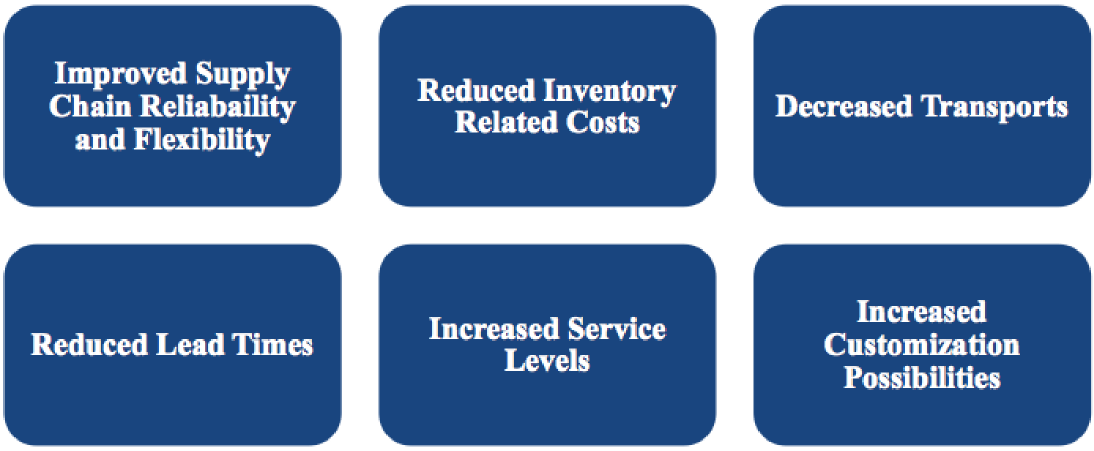


*Figure 28: An overview of the opportunities with distributed production using AM, included in the analysis*

### 5.2.1 Improved Supply Chain Reliability and Flexibility

According to the findings in section *2.3 Spare Parts in the Automotive Industry*, spare parts tend to have a more unpredictable demand. However, pressure is put on companies to provide high reliability when it comes to ensuring uptime for customer operations, which also is perceived by Volvo. Thus, both flexibility and reliability are needed, which according to Jonsson and Mattsson (2009) would be to have the ability to quickly respond to changes in customer demand whilst ensuring a high proportion of correct orders delivered at the right quality. To successfully perform this for Volvo's aftermarket is of importance since, as de Souza et al. (2011) argue, the aftermarket business is a high profit margin business for companies.

For these reasons, applying Volvo spare parts in the segmentation matrix constructed by Rushton et al. (2017), presented in section *2.4.1 Supply Chain Strategy*, would tend to place spare parts in the need of more agile or leagile supply chain, depending on the lead times of the spare parts. Section *4.2.1 Distribution Structure* describes Volvo's spare parts supply chain and reveals that a notable number of spare parts are being transported several times and stored in distribution centers before being delivered to dealers, thus several nodes are included in the supply chain. Furthermore, the supply chain is set up with defined processes and trying to work outside these has proven to be difficult to manage. One example mentioned is that urgent parts are most commonly not delivered directly from a supplier to a customer even if it is urgent, since these parts have gone missing in the past. Due to reasons as these, the flexibility and reliability could be considered to some extent as limited.

However, Khajavi et al. (2014), Li et al. (2017) and Rogers et al. (2016), all emphasize the potential flexibility improvements in supply chains adopting AM, since limited or no tooling is needed, there is low economies of scale and the technology can provide customized products with complex geometrics. This could potentially improve the flexibility in Volvo's spare parts supply chain by not only open up for new potential product offerings to customers but also create flexibility in the supply of the current product range, as producing parts where the current traditional machines are not available or not as efficient as AM.

By adding the aspects of moving production closer to the end customer, which according to Kothala (2015) would increase flexibility and agility in supply chains, this opens up for new potential spare parts supply chain flows for Volvo to use. These new possibilities are to take into account for flow optimization, as several steps in Volvo's spare parts supply chain could potentially be eliminated. This could be related to what Rushton et al. (2017) argued: when sourcing products with unpredictable demand locally, flexibility and reduced lead times could be achieved, which is further discussed in section *5.2.4 Reduced Lead Times*.

Another possible benefit of distributed production and AM is that the supply chain itself may enable greater transparency due to the related improvements in digital information flows. If a distributed production set-up with AM is pursued, it is possible that some of the issues with VOR orders, as discussed in section *4.2.6 Service Center and Transport Parts Management,* can be relieved, where dealers place emergency orders to speed up the delivery process despite the missing part not leading to a VOR. The dealers or customers could then in theory monitor the real time AM process of their requested spare part, and be given updates on their expected delivery times. This may in turn decrease the amount of VOR orders placed, as customers will be more aware of the estimated delivery time and will increasingly gain knowledge about the time to manufacture a part with AM. This aligns with the argumentation of Jonsson and Mattsson (2009), who claim that it may be just as important for customers to know when goods are arriving as to receive them quickly. The key points from this section can be seen in Figure 29.

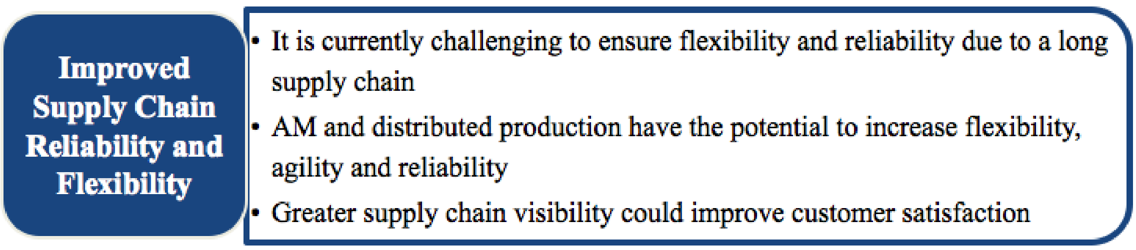


*Figure 29: Key points for improved supply chain reliability and flexibility*

### 5.2.2 Reduced Inventory Related Costs

All the inventory in Volvo's spare parts supply chain drives costs, and Chopra and Meindl (2016) stress this area by defining inventory as one of the supply chain drivers impacting on supply chain performance. However, currently at Volvo, several CDC, SDC and RDC are performing non-value adding stockholding. This stockholding, according to the description in section *4.2.5 Advanced Analytics Department* currently creates the difficult task to weight inventory holding costs, scrapping costs and cost of returns against order handling costs, rush freight costs, costs of lost sales and costs of bad will. A difficult task to perform, in order to find the lowest total cost. A decentralized supply chain structure will in general require greater total inventory in order to maintain the same service levels, but it is in combination with the opportunities of AM that distributed production the inventory costs could potentially be reduced.

As explained by Durão et al. (2017) and Meisel et al. (2016) distributed production with the use of AM could reduce inventory levels and inventory costs. This was also the result in the case study performed by Khajavi et al. (2014). By moving production closer to the end-customer, also the distance between the inventory kept in stock and the end-customer could be shortened. For the case study, this would entail having all inventories for the selected spare parts to Australia, in Australia. This relates not only to the potential flexibility aspects analyzed in section *5.2.1 Improved Supply Chain Reliability and Flexibility,* but also to the potential endeavor of printing parts on-demand. However, some inventory will reasonably be needed in stock due to the required time for the AM process as explained by Gibson et al. (2010) and the requirements on availability of spare parts as described in section 2.*3 Spare Parts in the Automotive Industry.*

However, it is reasonable to believe that just moving inventory closer to the point of consumption will not necessarily reduce stockholding costs at Volvo due to considerations of various cost drivers, as explained in section *4.2.5 Advanced Analytics Department.* The amount of savings in stockholding costs at Volvo, with an implementation of distributed production with the use of AM, could thus differ significantly due to these various cost drivers as segment, life-cycle, frequency and country, amongst others. As for instance, a heavy, low frequent spare part might amount for larger stockholding costs than a spare part which is lighter and high frequent, wherefore the former might be more suitable in case of inventory costs to consider, as distributed production could reduce the need of inventory holding. Parts included in the case study are smaller and lighter than many other parts in Volvo's spare part assortment, which could in terms of volume and weight be cheaper to keep in stock, and thus not as applicable for distributed production. A total cost evaluation is hence necessary. The key points from this section can be seen in Figure 30.

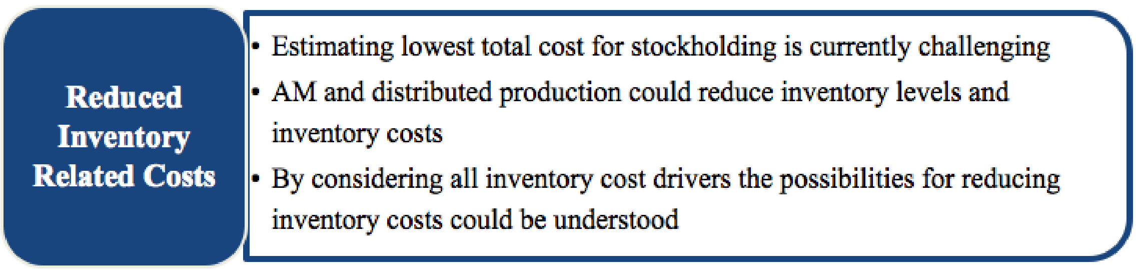


*Figure 30: Key points for reduced inventory related costs*

### 5.2.3 Decreased Transports

Another supply chain driver, defined by Chopra and Meindl (2016) and argued to be impacting on supply chain performance, is transportation. In the area of transportation Matt et al. (2014) expect rising fuel prices and upcoming emission regulations. This relates to Volvo as a multinational company, currently providing services world-wide by using various transport modes from the point of production to the point of use, as explained in section *4.2 Volvo Group Service Market Supply Chain*.

To consider further is that transports in cases are inefficient and cause disturbances in the spare parts supply chain at Volvo. As it is explained in section *4.2.4 Refill Department* delayed transports at Volvo cause insufficient availability at warehouses and in section *4.4.1 Background of Case Study* it is described that damages and loss of gods are effects of long transport chains. Even if transports are not a major cost at Volvo, they currently cause longer lead times according to the findings from section *4.4.1 Background of Case Study.*

Durão et al. (2017), Meisel et al. (2016) as well as Matt et al. (2014) argue that distributed production could reduce the need of transport, and in a case study performed by Khajavi et al. (2014) reduced transport costs were achieved with a more decentralized distribution structure. Thus, here are opportunities for not only reducing transport costs but also to contribute to a reduction of the effects derived from insufficient transports at Volvo. However, in the same way there are different cost drivers for inventory holding, there are different cost drivers for transport, which need to be considered if evaluating spare parts suitability for distributed production.

The opportunity of reducing transports is illustrated through the conducted case study. When comparing the current supply chain to the alternative scenarios presented in section *5.1.1 Distributed Production Scenarios for Case Study*, the transports could be reduced significantly, which can be seen in Table 9. In the two scenarios, on average, the possible reduction in transport distance for the selected parts could be above 90 %, as the only required transport would be between the AM production facility in Australia to the dealers, either directly or via the RDC. The findings are in proportion to weight and distance, as these are factors which drive the transport costs, besides mode of transport. Through applying distributed production in the alternative scenario on the selected parts, more than 14000 ton-kilometers could be eliminated each month, as an example. As the case study is focused on small and hence light plastic parts, the possible reductions in transport will have a significantly larger impact and hence opportunity when for example larger metal parts could be produced locally with AM. The key points from this section can be seen in Figure 31.

*Table 9: Average possible transport reductions based off the case study*

| | Average Transport Distance from Supplier to Dealer [km] | Average Potential Transport Distance Reduction with Distributed Production |
|---|---|---|
| Current Supply Chain (Sea) | 24434 | 92 % |
| Current Supply Chain (Air) | 19743 | 90 % |

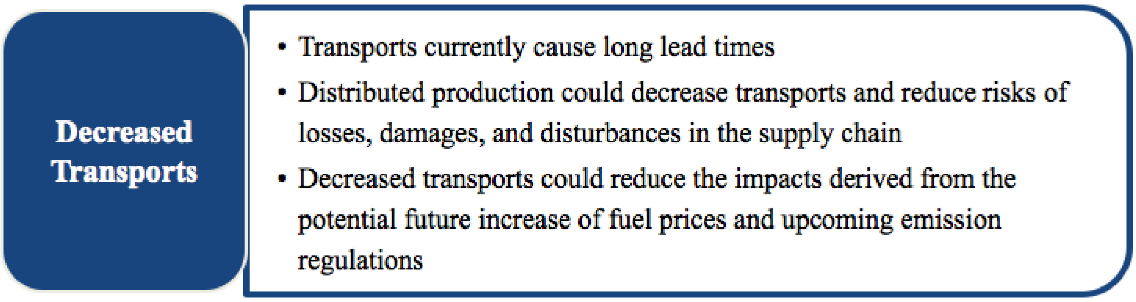


*Figure 31: Key points for decreased transports*

### 5.2.4 **Reduced Lead Times**

According to Khajavi et al. (2014) and Li et al. (2017), AM can enable lead time reduction, especially if it is possible to produce parts closer to the point of demand in the form of distributed production. This would hence lead to improved customer satisfaction, and ultimately profits, as described by Jonsson and Mattsson (2009). Through producing closer to the end-customer, the time from order to delivery of a part can be reduced through decreased transports and handling at various supply chain nodes.

One area of Volvo which could benefit from the reduced lead times which AM and distributed production could enable is for example the refill department, who manage the inventory decisions at the RDCs and SDCs. As described in section *4.2.4 Refill Department*, lead time delays are often caused by extensive handling, transport delays and lengthy customs inspections. Through producing locally, these times could be reduced or eliminated completely, which would lead to further lead time reductions. The shorter lead times could be kept while at the same time eliminating expensive air transportation, described in the same section.

Several suppliers in section *4.5.4 The view of AM and Distributed Production of AM Service Providers* argue that a main driver of distributed production with AM will be increasing demand from customers when it comes to logistics costs and timing. The possibilities for lead time reduction may hence be limited in today's market of distributed production, but increasing pressure from Volvo and other actors could improve the possibilities for the set up to be viable. This is further strengthened by Supplier C who argues that the AM industry will become decentralized as the market will require having access to the technology in different time zones to cater to on-demand production and hence reduce lead times for end customers.

The opportunity of reducing transport lead times is illustrated through the conducted case study. When comparing the current supply chain to the alternative scenarios presented in section *5.1.1 Distributed Production Scenarios for Case Study*, the transport lead time could be reduced significantly, as illustrated in Table 10. In the current supply chain, the average transport lead time from suppliers to customers for the spare parts amount to 56 days by air and 105 days by sea, between Ghent and Sydney. The span of the transport time and total lead time reduction presented will depend on several factors, such as complexity of the part and post-processing requirements. In addition, the time will be longer if a product is routed via the RDC as handling will add to the total lead time.

*Table 10: Average possible lead time reductions based off the case study in days*

| | Production Time | Transport Time to RDC | Total Lead Time to RDC | Lead Time Reduction |
|---|---|---|---|---|
| **Current Supply Chain (Sea)** | 24 | 82 | 105 | - |
| **Current Supply Chain (Air)** | 24 | 33 | 56 | - |
| **Distributed Production with AM** | 2-3 | 1-2 | 3-5 | 91 - 97 % |

In order to realize the reduced lead times, there are several factors for Volvo to consider. Firstly, the issues with maintaining availability for critical parts will not be solved by distributed production of AM as the production technique is not instant, and would require some inventory regardless. In aiding BOR however, AM and distributed production could be helpful as the customers can expect shorter lead times in case parts cannot be found throughout the current possible sources. Several challenges need to be considered for this to be viable, which will be discussed in the following section. The key points from this section can be seen in Figure 32.

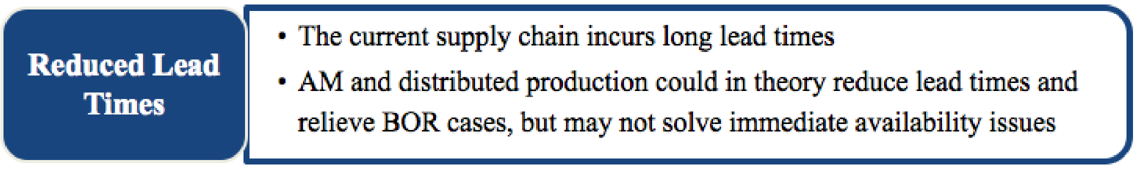


*Figure 32: Key points for reduced lead times*

### 5.2.5 Increased Service Levels

The service stock level is according to Jonsson and Mattsson (2009) the number of orders which are able to be delivered directly to customers from stock. As argued by Khajavi et al. (2014), companies often have to invest in costly spare parts supply chains, with inventories close to the point of consumption, to ensure the high level of fulfillment required by customers. This is as described in for example section *4.2.4 Refill Department*, where Volvo attempts to balance the tied-up capital in the down-stream supply chain against availability for customers. Through the AM opportunity of producing low volumes economically with distributed production, it may be possible to produce more of single parts and place them in inventory closer to the customer and hence aim for higher service levels. A larger number of different parts could be made available, but at lower inventory levels per part, which enables increased service levels for Volvos customers without increased cost.

As furthermore argued by Khajavi et al., (2014) and Li et al. (2017), AM theoretically enables production of any product, at any time and location as long as the right equipment is available. According to The AM expert at Chalmers, AM for spare parts is hence of interest as it companies essentially can provide any spare parts without stock, although it may be costly. However, as the expert also argues, automotive customers come to expect availability when there is a demand. Hence, the current printing speed and post-processing requirements may be an obstacle to a so called virtual-inventory, where only digital files are stored instead of physical parts. It may then be important to produce the parts closer to the point of demand, to maintain service levels without being impacted by complicated logistical flows. This is something that is mentioned in section *4.5.4 The view of AM and Distributed Production of AM Service Providers*, where a supplier argues that the flows will be more digital instead of physical in the future.

As presented in section *4.2 Volvo Group Service Market Supply Chain*, various departments have issues in securing service levels for customers, due to for example constraints in the automotive industry as a whole. VOR situations have been resolved with AM at Volvo, although this is not common. It is, according to the Swerea IVF AM expert, when critical parts enabling up-time can be produced through AM that the most opportunities can be realized. The current state of AM and for companies such as Volvo however, is best suited for producing more non-complex parts with low resistance demands, as argued by the AM expert at Chalmers. Hence, it may be the case that Volvo must first begin establishing AM processes and standards in order to improve their AM maturity and gradually move towards more critical parts for there to be a solid business case. This would be especially important in the case of a distributed production set-up.

Moreover, as discussed in section *4.2.4 Refill Department*, there are issues in securing service levels because of for example un-timely information in regards to sales-hikes, as the transport can take significant time from the CDC to an RDC. This could in theory be avoided through distributed production with AM, as parts could be produced on demand closer to demand. The key points from this section can be seen in Figure 33.

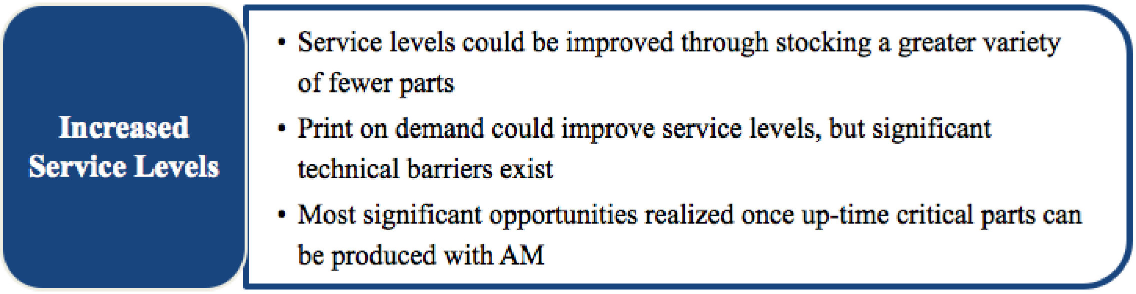


*Figure 33: Key points for increased service levels*

### 5.2.6 **Increased Customization Possibilities**

As argued by Khajavi et al. (2014) and Roger et al. (2016), AM opens up for increased customization of products for end customers. This as a result of limited tooling requirements and that design changes to 3D drawings could be easily performed (Khajavi et al., 2014), as well as that a large range of materials support AM (Li et al., 2017). When considering distributed production, both Kohtala (2015) and Matt et al. (2014) argue that demand for mass-customized parts will be a main driver for firms to adopt the supply chain structure, as distributed production will enable closer contact to end customers and hence better market knowledge. Some brands at Volvo have to some extent began offering customized parts with centralized AM, as revealed in section *4.3.2 AM Development and Initiatives*, but these are small-scale undertakings.

Along the lines of product argumentation, according to the AM expert at Chalmers and the Head of the AM Group at Swerea IVF, companies should revise their component thinking and re-design parts for AM. This, to draw use of possibilities such as part consolidation and weight reduction, as also argued by Oettmeier and Hofmann (2016), and realize significant opportunities of AM. In alignment with these findings are for example Volvo's design for AM project where these kinds of opportunities were experienced first-hand, and the courses relating to designing parts for AM which are initiated by Volvo, both presented in section *4.3.2 AM Development and Initiatives.*

However, as argued by the AM expert at Chalmers and the Head of the AM Group at Swerea IVF, the rework required to change a part can be extensive in time and resources due to that a changed drawing of a part will lead to different part characteristics which needs to be quality assured as a completely new part. Mass-customization as a driver for distributed production in terms of AM may hence be limited, due to these aspects. This is something that is important for Volvo to keep in mind, as despite the possible opportunities of AM, the idea of a customized print-on-demand solution could be far in to the future. If this becomes more viable on a larger scale however, it could impact the possibility to develop new business models, as stated by AM expert at Chalmers, which is something for Volvo to consider further as the barriers to mass-customization decrease. The key points from this section can be seen in Figure 34.

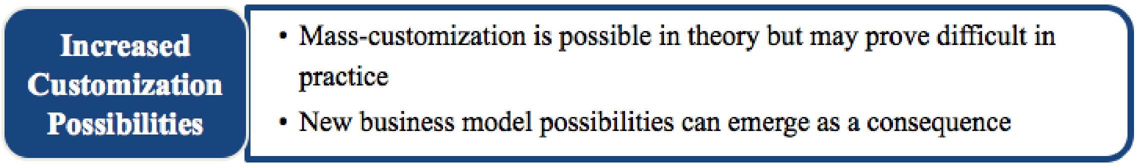


*Figure 34: Key points for increased customization possibilities*

### 5.2.7 Summary of Opportunities

In Figure 35 below a compilation of the opportunities of distributed production of spare parts using AM for Volvo is presented. Below each opportunity the key points of interests are listed. The potential opportunities can vary in their applicability over time, and will relate to the AM strategy pursued internally at Volvo, as well as external development in for example AM technology and the supply market. Some opportunities are interrelated, such as decreased transports and reduced lead times. The opportunities also differ in terms of being measurable, as it will for example be easier to document improved service levels on a certain part as opposed to general improvement in supply chain flexibility. It may be important for Volvo to measure and document concrete supply chain improvements if a distributed production set up with AM is pursued, in order to sustain commitment throughout the organization.

| | |
|---|---|
| **Improved Supply Chain Reliability and Flexibility** | • It is currently challenging to ensure flexibility and reliability due to a long supply chain<br>• AM and distributed production have the potential to increase flexibility, agility and reliability<br>• Greater supply chain visibility could improve customer satisfaction |
| **Reduced Inventory Related Costs** | • Estimating lowest total cost for stockholding is currently challenging<br>• AM and distributed production could reduce inventory levels and inventory costs<br>• By considering all inventory cost drivers the possibilities for reducing inventory costs could be understood |
| **Decreased Transports** | • Transports currently cause long lead times<br>• Distributed production could decrease transports and reduce risks of losses, damages, and disturbances in the supply chain<br>• Decreased transports could reduce the impacts derived from the potential future increase of fuel prices and upcoming emission regulations |
| **Reduced Lead Times** | • The current supply chain incurs long lead times<br>• AM and distributed production could in theory reduce lead times and relieve BOR cases, but may not solve immediate availability issues |
| **Increased Service Levels** | • Service levels could be improved through stocking a greater variety of fewer parts<br>• Print on demand could improve service levels, but significant technical barriers exist<br>• Most significant opportunities realized once up-time critical parts can be produced with AM |
| **Increased Customization Possibilities** | • Mass-customization is possible in theory but may prove difficult in practice<br>• New business model possibilities can emerge as a consequence |

*Figure 35: A compilation of the opportunities with distributed production using AM for spare parts at Volvo*

## 5.3 Challenges with Distributed Production of Spare Parts using AM

According to Oettmeier and Hofmann (2016), AM has several technical limitations, and as argued by Rogers et al. (2016) AM may also cause organizational issues for companies. In addition, distributed production entails challenges such as coordination and information management, as argued by Durão et al. (2017) and Srai et al. (2016). When a distributed production set-up for their spare part supply chain using AM is considered by Volvo, the associated challenges are important to consider, both in terms of determining whether distributed production is a viable and beneficial alternative for certain parts, but also to understand the associated risks. Six potential challenges with distributed production were described in section *2.2.3 Potential Challenges with Distributed Production*, and empirical findings also indicated on several of these, wherefore these six challenges will be included in the analysis and analyzed related to Volvo's spare parts supply chain. However, some of these challenges will in the analysis be presented as integrated due to their close relation. Additionally, from the empirical findings, network and interdependencies as well as organizational maturity indicated to be challenges for distributed production, wherefore also these challenges will be included in the analysis and analyzed related to Volvo Groups spare parts supply chain. A compilation of the final six challenges included can be seen in Figure 36. A summary of the challenges and their respective key points will round off the section.


*Figure 36: An overview of the challenges with distributed production and AM, included in the analysis*

### 5.3.1 Network Interdependencies and Risks

As described in section *2.1.3 The Growth of the AM Industry*, applying AM will impact the network structure of a company. By working with new actors and gaining access to new resources, AM competence and knowledge could be shared between companies. As Wohlers (2016) explain, there could be AM machine manufacturers, AM material providers, AM service providers and customers of AM services and products etc. in such a network. Volvo hence needs to situate the company in this network, and define the company’s role in it whilst ensuring access to sufficient AM and distributed production competency from other actors in this network. This aligns with the reasoning by the AM Expert at Chalmers and the findings from Swerea IVF in section *4.5.2 AM Conference at Swerea IVF*, who argues that companies need to consider the whole AM-network in order to be successful with AM.

As explained in *4.1 Volvo Group*, the company is already a multinational company in a large network of actors, which would potentially increase the complexity further. This relates to the arguing by Rushton et al., (2017), who explain that distant sourcing will require different supply chain structures than locally sourced goods, which would be the case with distributed production. This could further add to complexity in Volvo's network. Hence, there could be increased need of co-ordination efforts. Furthermore, by changing network structure, the current relationships also need to be considered and how Volvo could be impacted by changes on these.

Based on information from section *4.3.2 AM Development and Initiatives* it could be argued that Volvo already have started the process of developing its AM network since the section describes that Volvo has connections to various AM service providers. However, the decision whether to produce with AM in-house or use an outsourced solution is not yet decided, wherefore Volvo's role and position in an AM network could reasonably change over time. However, regardless of what role Volvo decides to strive for, the company will reasonably be dependent on other actors which are linked to the company, and according to the reasoning by Chopra and Meindl (2016) impact on the drivers of supply chain costs, such as foremost sourcing, but also other drivers as information and pricing.

From section *4.3.3 Internal Competency Development* it becomes clear that Volvo is affected by internal interdependency between actors within the company. It could be argued that similar interdependencies will occur between Volvo and other actors in the AM network, if proceeding with AM and/or distributed production. Thus, it becomes important to ensure sufficient relationships and be prudence for who to do business with. In section *4.3.4 AM from a Purchasing Perspective* it is explained that the purchasing department at Volvo tries to avoid collaboration with AM service providers which have a higher risk of leaving the market in the next coming years, however it is explained that predicting things as these are difficult, wherefore the challenges and related risks need to be understood and evaluated by Volvo.

Moreover, Van Weele (2014) explained that product availability, number of suppliers, cost of changing suppliers, the market structure, substitutes and geographic distance are all factors impacting supplier risks. AM could be seen as a fairly rapidly developing technology and according to Chalmers (2018) and the AM expert at Chalmers there is a threat of new actors entering the AM industry, such as logistical providers, which could change network structures. Furthermore, the application of distributed production, according to the suppliers from section *4.5.4 The view of AM and Distributed Production of AM Service Providers,* could be seen as in its more initial phase, wherefore developments reasonable are to come. Due to reasons as these, the supplier risks could arguably be notable. Some mentioned supply risks are defined by Chopra and Meindl (2016) and van Weele (2014) as: Technical & Performance Risks, Commercial Risks, Contractual Risks, Information Risks, Dependence Risks and Co-ordination Risks. All these are risks which Volvo must consider carefully if proceeding with AM and distributed production.

Another aspect worth considering in the future may be that spare parts of different characteristics may require or benefit from different types of supplier relationships, as presented by van Weele (2014). For example, the degree of criticality of parts, as argued by the AM expert at Chalmers, may have an impact on which supplier relationship to pursue. A more mature technology and less critical parts may imply that a transactional relationship is preferable in order to ensure cost-efficiency, while less mature technologies with critical parts in the future may demand a partnership or similar to ensure performance. As argued in section *4.3.2 AM Development and Initiatives*, this time frame may for example depend on whether the parts are of plastic or metal, due to their different characteristics.

Furthermore, to avoid risks and overcome challenges related to Volvo's AM network position and potential interdependencies, an understanding of the network and the AM industry will be to strive for. In section *2.1.3 The Growth of the AM Industry*, it becomes clear that the AM Industry has developed rapidly recently, as new possibilities are opened, and new actors are entering the market. However, the markets development has according to the findings in section *4.3.4 AM from a Purchasing Perspective* created regional differences in case of AM knowledge, competence and resource availability, which reasonably could limit the opportunities for distributed production at Volvo. Lack of AM actors or expensive raw materials in a specific region are for instance potential market constraints. Volvo have to be aware of these constraints and follow future developments in order to secure knowledge, competence and resources. According to Gartner's Hype Cycle in section *2.1.4 Future Expectations on the AM Industry*, AM is expected to bring new business opportunities also in the upcoming years, which will most reasonably impact the market development, giving Volvo new AM actors to work with. The key points from this section can be seen in Figure 37.

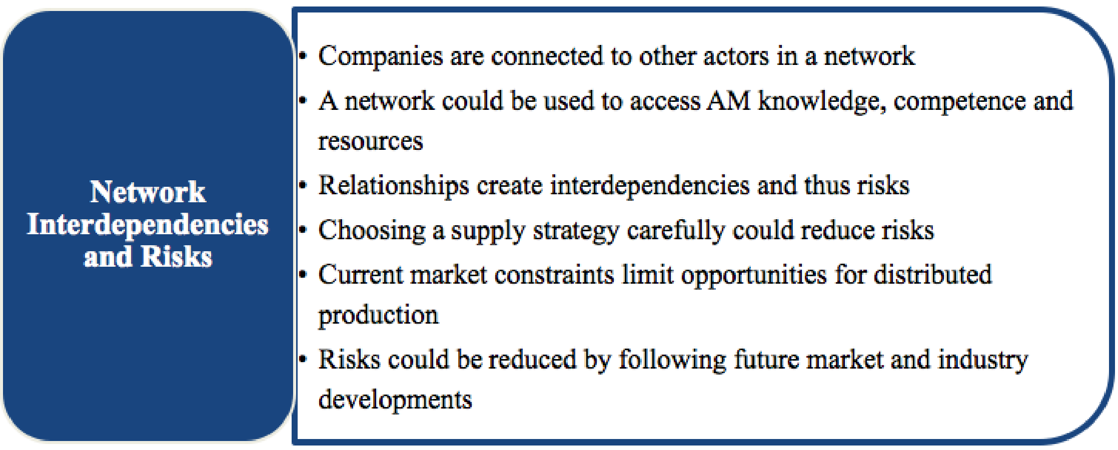


*Figure 37: Key points for network interdependencies and risks*

### 5.3.2 Governance, Ownership and Information Management

Srai et al. (2016) clarify that questions related to governance and ownership in a distributed production are of high importance. Section *4.3.2 AM Development and Initiatives* shows that AM has until recently has been considered as a fairly new technology to the company, wherefore Volvo Group Trucks Technology (GTT) has had a larger involvement in the process of applying the technology internally, which includes involvement in the different grass root initiatives. However, as explained in section *4.5.2. AM Conference at Swerea IVF* the GTT representative is not aware of all AM initiatives within Volvo and the company is lacking a strict governance structure for AM. As the number of initiatives has increased, the AM knowledge has grown and been more spread out throughout the company and it is arguable that other actors internally could take stronger positions within the AM developments at Volvo. Therefore, governance and ownership questions have become important AM questions at Volvo, wherefore a cross functional work group has been created, aiming for a more coordinated AM approach.

Thus, it is clear that Volvo has some work ahead in order to decide on governance and ownership when developing AM within the company. Therefore, to extend further and apply distributed production with the use of AM would most reasonable be a notable challenge with consideration to governance and ownership. This since distributed production would have a significant impact on the spare parts supply chain structure and the many employees involved in the different stages of the supply chain. From section *4.2 Volvo Group Service Market Supply Chain* it is revealed that employees in Volvo's spare parts supply chain currently have various responsibilities in case of ownerships but also defined standardized processes to follow, which are not established or adapted for AM nor distributed production.

With distributed production, new actors need to be involved, new tasks will occur, and new processes will be necessary - all aspects which need to be taken into account when deciding on who should perform what, who should be responsible and how should information be shared. This aligns with the argumentation of the AM expert at Chalmers who emphasized the ownership question and argued that companies must on a strategic level decide on who owns which processes. However, complexity could be to expect as the company functions could not be viewed as isolated functions due to the many interdependencies between them, as described in section *4.3.3 Internal Competency Development*, governance. Thus, governance and ownership questions could potentially become even more complicated questions to decide on and follow efficiently.

As Matt et al. (2014) explain, one of the downsides with a more distributed production structure is the increased complexity. Since different distributed production structures could be used, which can be seen in Table 5, the level of complexity could vary. However, in all cases sufficient information management could be argued as crucial since information is one of the main drivers in a supply chain, set by Chopra and Meindl (2016), and has the potential to strongly affect other supply chain drivers. As described in section *4.2 Volvo Group Service Market Supply Chain*, Volvo uses defined processes in the supply chain and the information network is structured based on the current spare parts flows. Before any changes on the supply chain can be made, all actors involved need to be considered in the information network, such as internal actors in Volvo's supply chain as well as the external actors connected to Volvo.

By creating new flows for spare parts through distributed production new information connections will be necessary. The complexity also concerns the new flows for distributed production spare parts which will require new ways of handling this, whilst simultaneously ensuring the flows of the spare parts that are outside the scope of suitable for distributed production and should be handled according to the current supply chain processes. Ensuring sufficient information management between and to the different production sites will be another concern, according to Durão et al. (2017) and Srai et al. (2016). The impact this will have on quality assurance will be further analyzed in section *5.3.3 Quality Management.* However, as elaborated in section *5.3.1 Network Interdependencies and Risks* there are various potential supplier relationships to use, an aspect to take into account in the question of information management.

An example of a project which aims to put AM produced spare parts into practice is the current pilot described in section *4.4.1 Background of Case Study*. Here, the Australian market is chosen as suitable as its national department more agile. By executing the pilot, several questions related to governance, ownership and information management for AM could be elaborated. However, to make use of the learnings, it would be important that the results from the pilot are documented and spread throughout Volvo, in order to inspire other departments to pursue their own initiatives within AM but also to learn from shortcomings and success factors. The key points from this section can be seen in Figure 38.

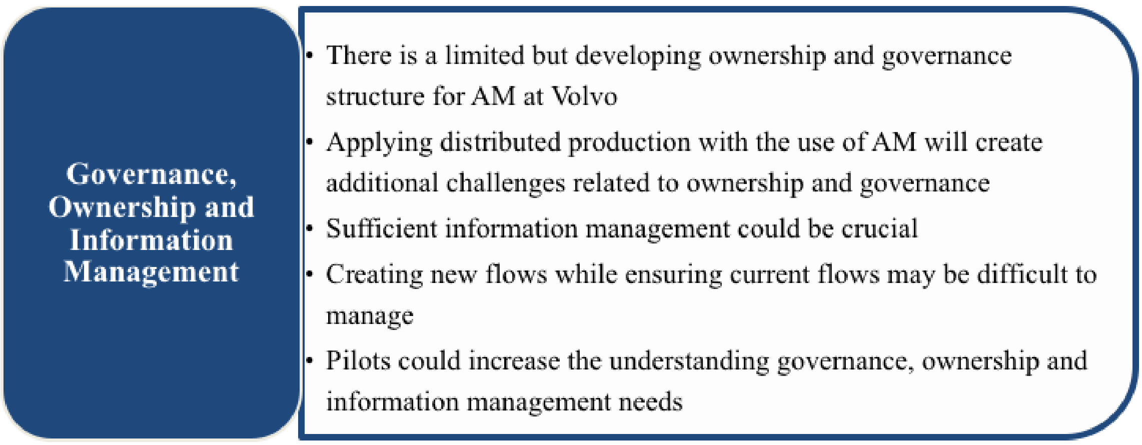


*Figure 38: Key points for governance, ownership and information management*

### 5.3.3 Quality Management

When considering distributed production of AM produced spare parts, theoretical and empirical findings show that quality management is a main area of concern. Firstly, AM has technical limitations in regards to quality, as argued by Durach (2017). In relation to this are also precision parameters when it comes to post processing and surface finishing, as highlighted by Oettmeier and Hofmann (2016). These are challenges which Volvo also have identified, as argued in section *4.3.1 Service Market AM Strategy.* Understanding technical limitations of AM such as quality is crucial to the successful adoption of AM according to Mellor et al. (2014) and the Head of the AM Group at Swerea IVF.

As argued in section *4.3.3 Internal Competency Development,* parts produced through AM may have different material characteristics compared to the same parts produced with traditional manufacturing techniques. This makes quality testing a crucial element, as product characteristics may change drastically as a consequence of this. This could imply that some of the opportunities argued in section *2.1.1 Potential Opportunities with AM*, such as flexible product designs, may not be applicable in all situations. Changes to a drawing will lead to a part with new characteristics and hence needs to be quality certified again in order to be used as a functional part. This is further strengthened by the Head of the AM Group at Swerea IVF, who argues that there is great effort put in to securing quality for every changed drawing.

This is further highlighted in section *4.5.1 The View of AM and Distributed Production of an AM Expert at Chalmers,* as the AM expert at Chalmers argues that in order to ensure quality compliance in AM you have to be able to ascertain quality in all physical and digital flows enabling the production of a part. Essentially, different AM machines cannot be used and expected to produce identical parts, as there are technical differences within the machines. This is also highlighted by some suppliers in section *4.5.4 The view of AM and Distributed Production of AM Service Providers,* where they reveal that despite using the same machines, different outcomes cannot be guaranteed. It is hence important to ensure robust processes, as argued by both the Head of the AM Group at Swerea IVF and other actors in section *4.5.2 AM Conference at Swerea IVF.*

In line with this reasoning are findings from section *4.5.2 AM Conference at Swerea IVF,* and as argued by the AM expert at Chalmers and the Head of the AM Group at Swerea IVF, that all parts of the AM eco-system including but not limited to the powder supply, the machine, the set-up and the after-processing have to be quality assured for each part. Therefore, Volvo would need to perform quality assurance for each AM-hub considered for distributed production, for each spare part separately which would reasonably become both costly and take time, as argued by Srai et al. (2016). Additionally, there are uncertainties in quality assurance when it comes to distributed production itself (Durão et al., 2017; Srai et al., 2016). Durão et al. (2017) stress the complexity of assigning ownership of quality performance in distributed production, and that there is a correlation between the degree of decentralization and the amount of decisions that the decentralized production site has to take in regards to quality. The AM expert at Chalmers further argues that a suitable strategy to pursue for companies may hence be to start adopting AM and distributed production for non-critical and non-visible parts.

The question of quality could however largely be correlated to the sourcing strategy pursued in regards to AM. As argued by the AM expert at Chalmers however, if companies choose to partner with an AM service provider, who for example manufactures parts in geographically distributed locations, Volvo can demand quality compliance from them independent of site. The risks of this however is that if quality cannot be guaranteed, it is ultimately Volvo who will suffer from unsatisfied customers and potential bad will and lost sales. According to van Weele (2014), there are supply risks in companies becoming dependent on sufficient quality levels from certain suppliers. If a distributed production set-up is considered, this may mean selecting a supplier from a pool of alternatives, which is located in the closest geographical proximity to the point of demand. In this case, the sourcing strategy will turn towards multiple sourcing, which may further add to the quality management risks argued above. It could be considered whether the growth of IoT and the related possibility for Volvo to monitor performance from a distance through sensors as argued by Srai et al. (2016) and in section *4.3.2 AM Development and Initiatives*, could aid in mitigating this problem. However, the issue of securing quality remains a significant challenge for the viability of distributed production today.

In regards to quality assurance, the suppliers stress in section *4.5.4 The view of AM and Distributed Production of AM Service Providers*, that this can be monitored by the customer on demand through performance reports and documentation. They also largely refer to ISO standards. However, according to the Head of the AM Group at Swerea IVF there are lacking standards within the AM industry, and these will take time to specify and put in to practice. This lack of standardization is hence a risk for Volvo, who must ensure themselves that the suppliers they are working with meet Volvo's own requirements. This may also cause a lock-in effect, where a quality assured supplier for a certain part is chosen to provide the entire world market from a specific hub, limiting the potential adoption of distributed production and AM. The key points from this section can be seen in Figure 39.

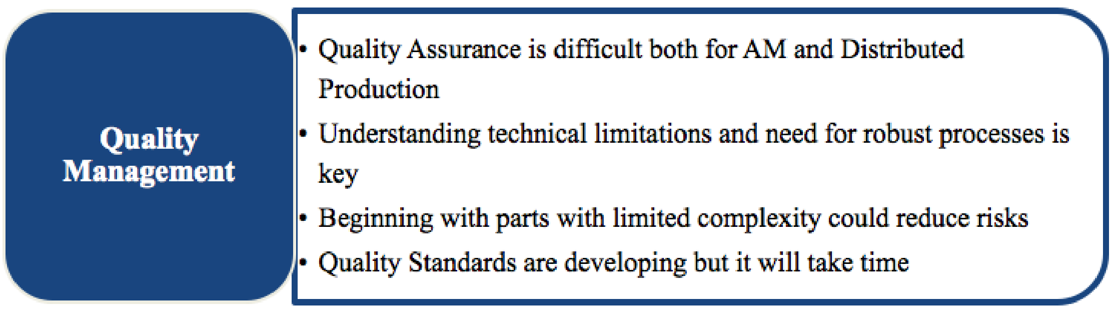


*Figure 39: Key points for quality management*

### 5.3.4 Digital Infrastructure and Copyright Infringement

One area which requires attention when considering distributed production of spare parts produced through AM is the digital infrastructure which this requires, as argued by Durão et al. (2017) and Srai et al. (2016). In order to successfully apply AM, and especially for distributed production, all parts need to have corresponding 3D-files. Srai et al. (2016) emphasize the importance of AM software and CAD-competence in relation to this to ensure successful creation, modification and distribution of AM files. This may be a challenge for Volvo in ramping up their AM commitment, as there are currently to some extent data reliability issues when it comes to spare part drawings within the company as argued in section *4.3.3 Internal Competency Development.* This barrier is a challenge for distributed production with AM, which Volvo need to consider.

Moreover, as argued by de Souza et al. (2011), the automotive industry is characterized by long product life cycles. Although life-cycles may be decreasing in length, this factor will still be of significance for Volvo as they will need to continue to supply demand with spare parts for old vehicles. Producing new parts for newer vehicles which are adaptable to AM is important, but it will not solve the immediate issues with missing drawing for current spare parts. This is hence currently and may continue to be an obstacle for distributed production with AM. Through securing that AM-compatible drawings are used for new parts; this issue can be avoided in the future. This is in line with the reasoning of Srai et al. (2016), who argue that as technologies enabling distributed production to continue to evolve, products will become increasingly considered as data. This is further expressed by suppliers in section *4.5.4 The view of AM and Distributed Production of AM Service Providers.*

In addition to the required existence of 3D files, as argued by Gibson et al. (2010), there are several steps between a 3D drawing and being able to produce said part with AM. Volvo also partly use certain CAD-software which is not supported by AM, as argued in section *4.3.3 Internal Competency Development.* Manual rework is hence needed. This increases the complexity and slows down AM adoption, and further adds challenges to a distributed production set up. According to the AM expert at Chalmers, it is of outmost importance to have digital files ready for AM, where all parameters are secured. Without this in place, the entire process will be slowed down and a bottle-neck will be created at this point of the AM process. In this case, the entire idea of print-on demand may become unviable, as significant time would be added to the process.

As already elaborated in section *5.3.2 Governance, Ownership and Information Management,* standardized processes for AM at Volvo is not yet established which also includes processes for the digital flows. This means that it may be difficult to control and manage the various initiatives and data sharing. It could hence be worth considering how this issue is to be approached by the company as a whole. According to Mellor et al. (2014), companies need to adopt their operation systems, such as align and change internal processes, to successfully implement AM. An overall company decision on how the issue of secure digital transfer may therefore be necessary. This, not only to protect company information but also to create a standardized solution to speed up and ease AM adoption.

Furthermore, the risk of digital transferring of files may depend on the relationships which are established with AM service providers. As argued in section *4.3.4 AM from a Purchasing Perspective,* there are both opportunities and challenges with different forms of supplier relationships for Volvo when it comes to AM of spare parts. If more transactional relationships are pursued, data transfer and management may become more difficult to control as more actors are involved and the loyalty and commitment of the suppliers may not be as high. One risk of outsourcing production is according to Chopra and Meindl (2016) the possibility of sensitive information or intellectual property leaking to competitors or other actors. In the case of AM and distributed production more external contact points are required if the closest possible supplier is used, which hence increase these risks. Srai et al. (2016) stress that risk in this information sharing must be factored in and guide the decision in implementing distributed production. In addition, in the case of AM it may also be important to protect for example 3D-drawings being transferred to end consumers, as argued in section *4.4.1 Background of Case Study.* In section *4.5.4 The view of AM and Distributed Production of AM Service Providers,* one supplier further highlights that data regulation is key in distributed production and that contracts need to be prepared carefully. In addition, the costly investments in digital infrastructure as described by Srai et al. (2016), could also largely be dependent on what form of supplier relationships are pursued or if an in-housed AM solution is chosen in the future.

However, one way to manage secure transfer of digital files is investigated by Volvo as argued in section *4.3.2 AM Development and Initiatives*, as suppliers of tracking and controlling AM at a distance have been evaluated. A similar type of service is also presented by Stackpole (2013), who discusses the possibility to use an end-to-end service where all parts of the AM supply chain are managed externally. These may prove as valuable and viable services in the near future, to ease the adoption phase of AM for spare parts and at the same time ensuring secure transfer of data. At the same time, large investments in AM machine and surrounding facilities are avoided. However, these services may strain the business case for AM in the future, depending on requested capacities and market development. On the other hand, there is currently not a large cost focus on AM at Volvo due to the extensive range of opportunities as presented in section *2.1.1 Potential Opportunities with AM* and Volvo's focus on customer availability. These types of services may hence be applicable in the short-term, but their viability in the future should be assessed as internal AM maturity increases. The key points from this section can be seen in Figure 40.

**Digital Infrastructure and Copyright Infringement**

- Currently uncertainties in existence of digital data and flows
- Securing AM compatible 3D-files for spare parts is of importance
- Standardized ways of securing digital data flows could mitigate IP risks
- Risk level is dependent on chosen supply strategy

*Figure 40: Key points for digital infrastructure and copyright infringement*

### 5.3.5 Organizational Maturity

When considering distributed production of spare parts using AM, several changes are required to an organization. Not only is a new technology in the form of AM used, but the supply chain structure in itself is changed, as argued by Rushton et al. (2017). To simultaneously adopt these changes may be difficult unless there is a sufficient level of organizational maturity in the company. Volvo has varied levels of internal AM knowledge as argued in section *4.3.3 Internal Competency Development* and in section *4.3.5 Internal AM Studio at Volvo.* This will be a challenge when attempting to ramp up the use of AM, as maturity and in-house competence can be key factors to successful adoption as argued by the AM expert at Chalmers, by Mellor et al. (2014) and by Bengtsson and Karlström (2017).

This line of reasoning is further strengthened in section *4.5.1 The View of AM and Distributed Production of an AM Expert at Chalmers*, where a stepwise improvement is suggested, and gradual AM knowledge is improved. This corresponds to the strategy pursued by Volvo, where a gradual development of manufacturing prototypes and production fixtures with AM to spare parts is currently in action as described in section *4.3.2 AM Development and Initiatives*. The Head of the AM Group at Swerea IVF highlights that company engineers will need to understand the technical opportunities and challenges with AM itself in order to draw benefit from it, which is why investment into this kind of education is necessary. This is something which is recognized by Volvo, and as argued by a Volvo representative in section *4.5.2 AM Conference at Swerea IVF*, education and a fearlessness to do trial-and-error projects will be important for the company to continue to increase the use of AM and consider pursuing a distributed production set-up in the future.

As argued by another Volvo representative in section *4.5.2 AM Conference at Swerea IVF*, AM may require a change in culture as it needs to gain acceptance within the different departments to be put into practice. The relative stiffness of a large organization is therefore an obstacle in implementing any new technology, due to solid processes and many stakeholders. Internal interdependencies are evident within Volvo as presented in section *4.3.3 Internal Competency Development.* The risk of AM not gaining enough acceptance within companies hence becomes an obstacle to adoption, as argued by AM service providers in section *4.5.4 The view of AM and Distributed Production of AM Service Providers.* This is to some extent evident within Volvo, and felt by the service market department. Production of new products remains a priority for many departments within Volvo, which may limit the interest in AM as its opportunities are best suited for the low-volume parts which align more closely with the interests of the service market departments. Due to the discussed interdependencies, the acceptance may be important within all departments in order for further successful AM adoption.

The framework for measuring organizational maturity in terms of AM, proposed by Bengtsson and Karlström (2017) includes strategic, organizational, supply chain, operational and technological AM maturity. However, besides having sufficient maturity levels, it may also be important to have agility in the company, as described and argued by Rushton et al. (2017) and elaborated on in section *5.2.1 Improved Supply Chain Reliability and Flexibility*. It could however also be argued that agility is a form of maturity, which captures and enables change. Without having the agility to adopt and apply the new technology in to standardized processes leading to parts actually reaching the end customers, AM knowledge in itself is not as valuable. This is why pilots and new initiatives, such as argued in section *5.3.1 Network Interdependencies and Risks*, is important. The need for internal examples from within Volvo is requested by various internal stakeholders and will most reasonable lead to greater awareness of the technology and its potential. This will lead to a greater company wide acceptance and hence a quicker and more effective integration of AM in Volvo's processes.

Agility is according to Kohtala (2015) furthermore especially important in a distributed production set-up. Hence, it is important for Volvo to not only consider gaining the technical knowledge in AM, but also begin considering how this technology will be managed within the company, how the processes can be adapted and how enough agility can be built in to a large organization to capture innovation and put it in to practice. The distributed production set up in combination with the use of AM will further add to this complexity, which is why the importance of the organizational aspects increases. The key points from this section can be seen in Figure 41.

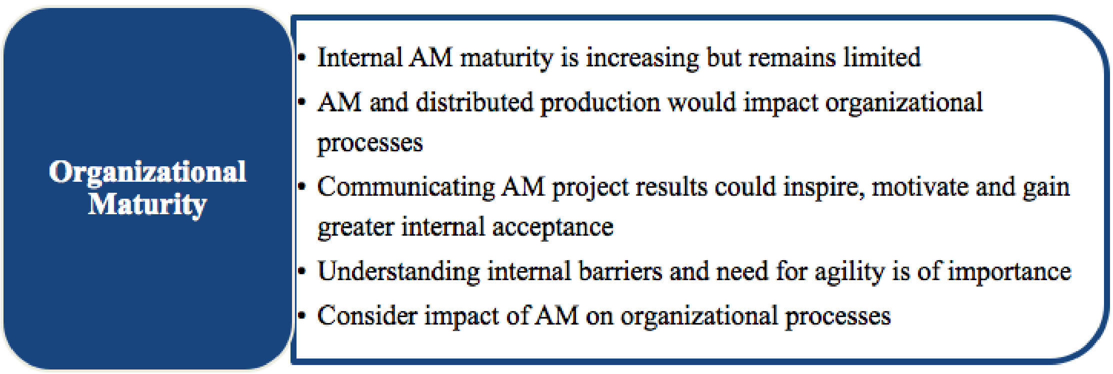


*Figure 41: Key points for organizational maturity*

### 5.3.6 Return on Investment

Another challenge of distributed production of spare parts using AM are the low economies of scale impacting the return on investment. This challenge relates to AM technology itself, as argued by Oettmeier & Hofmann (2016), and in using distributed manufacturing economies of scale may reasonably be even lower, as production is decentralized, and certain production locations supply certain markets as argued by Srai et al. (2016). This is especially true in the case of an in-housed solution, as highlighted by the AM expert at Chalmers and Thomas (2016). As described by Li et al. (2017), there are many different types of AM techniques, which require different machines and knowledge. Investing resources in to being able to utilize all these techniques successfully would prove extremely costly for Volvo, who may also suffer from low capacity utilization as argued by the Chalmers AM expert. This is especially the case for distributed production. Besides investment in capital and competence, the information sharing, and coordination requirements could also prove costly.

In a case study with AM and distributed production, Khajavi et al. (2014) found that a centralized solution was the most beneficial from a cost perspective, but argued that as the technical and financial aspects of AM machines improve in factors such as autonomy, quality and cost, a decentralized solution is likely to become economically viable. AM machines will however not drastically decrease in cost in the near future, as argued by the AM expert at Chalmers and the Head of the AM Group at Swerea IVF. Through using AM service providers, the capacity and hence costs of AM-hubs are shared with other providers, making each part produced cheaper. This would also decrease the risk Volvo would be otherwise be exposed to, of for example technologies becoming obsolete. This may also be the case if current traditional suppliers are used to partner for AM, as it would likely require investments or commitment from Volvo’s side in to AM equipment. On the other hand, the current suppliers have knowledge and tools for after-processing, as argued by the AM expert at Chalmers.

Furthermore, when considering a distributed production set-up with AM it is important to consider the range of suppliers which may be used. First of all, Volvo’s purchasing power may be low if many different suppliers are chosen for a partnership or for different assignments. As a result of this, their orders may not be prioritized. In addition, if the closest possible supplier or site is to be used, it may not always be the most cost-efficient total solution due to differences in supplier offerings.

Regardless of whether an in-housed or outsourced solution is chosen, it is important for Volvo to consider the value which a distributed production set up with AM would bring. For example, it is significant to assign a value to for example reduced lead times to customers and how this would improve customer satisfaction, as described by Jonsson and Mattsson (2009). This is important in order to determine the business value for a distributed production set-up for AM, as despite cost per part not being a large part of Volvo’s strategic focus for AM in the service market right now, it is still important to consider in the future. This aligns with the recommendations proposed by Khajavi et al. (2014) who argue that it is important for companies to perform a cost benefit analysis before deciding on a distributed production set up, as there are different variables to consider for each specific case. Different parts will have different returns on investment with AM and distributed production, which will also depend on the development of AM and the market opportunities for distributed production and AM. The key points from this section can be seen in Figure 42

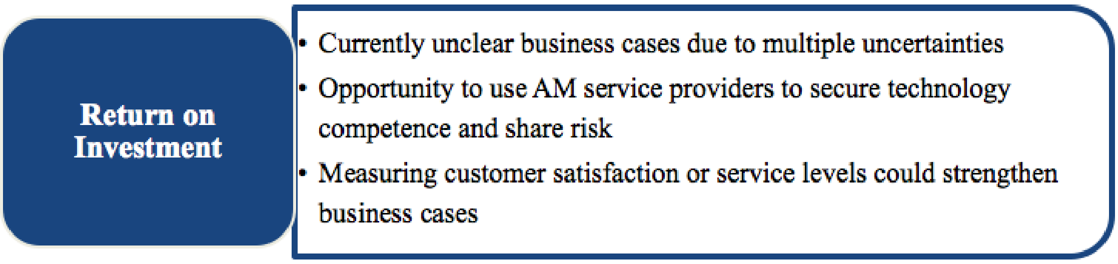


*Figure 42: Key points for return on investment*

### 5.3.7 Summary of Challenges

In Figure 43, a compilation of the challenges of distributed production of spare parts using AM for Volvo is presented. Below each challenge the key points of interests are listed. The potential challenge can vary in their severity and risk of occurrence over time, and will relate to the AM strategy pursued internally at Volvo including the supply strategy, as well as external development in for example AM technology and AM eco-system.

**Network Interdependencies and Risks**

- Companies are connected to other actors in a network
- A network could be used to access AM knowledge, competence and resources
- Relationships create interdependencies and thus risks
- Choosing a supply strategy carefully could reduce risks
- Current market constraints limit opportunities for distributed production
- Risks could be reduced by following future market and industry developments

**Governance, Ownership and Information Management**

- There is a limited but developing ownership and governance structure for AM at Volvo
- Applying distributed production with the use of AM will create additional challenges related to ownership and governance
- Sufficient information management could be crucial
- Creating new flows while ensuring current flows may be difficult to manage
- Pilots could increase the understanding governance, ownership and information management needs

**Quality Management**

- Quality Assurance is difficult both for AM and Distributed Production
- Understanding technical limitations and need for robust processes is key
- Beginning with parts with limited complexity could reduce risks
- Quality Standards are developing but it will take time

**Digital Infrastructure and Copyright Infringement**

- Currently uncertainties in existence of digital data and flows
- Securing AM compatible 3D-files for spare parts is of importance
- Standardized ways of securing digital data flows could mitigate IP risks
- Risk level is dependent on chosen supply strategy

**Organizational Maturity**

- Internal AM maturity is increasing but remains limited
- AM and distributed production would impact organizational processes
- Communicating AM project results could inspire, motivate and gain greater internal acceptance
- Understanding internal barriers and need for agility is of importance
- Consider impact of AM on organizational processes

**Return on Investment**

- Currently unclear business cases due to multiple uncertainties
- Opportunity to use AM service providers to secure technology competence and share risk
- Measuring customer satisfaction or service levels could strengthen business cases

*Figure 43: A compilation of the challenges with distributed production using AM for spare parts at Volvo*

# 6. Discussion

This study can serve as a foundation for the viability of distributed production with the use of AM for Volvo Group. Volvo could draw use of the findings by gaining increased knowledge of the presented opportunities and challenges for distributed production with the use of AM.

For the presented findings, both theoretical and empirical information have been taken into account, and by cross-referencing theoretical and empirical sources, similar opportunities and challenges have become visible. Multiple empirical sources from interviews, workshops, study-visits and correspondence with AM service providers strengthen the reasoning and contribute to the fulfillment of the purpose of the study. The theoretical framework is built upon recent publications on AM and distributed production to avoid obsolete information, as well as established and accepted theory on supply chain management and spare parts in the automotive industry.

However, important to notice is that AM and distributed production are new topics, wherefore it is difficult to determine the reliability of this theory and the related findings. This was especially notable for the area of distributed production, as limited theory and case studies was published, hence potentially impacting on the objectivity and reliability in this area of the study, due to dependency on few theoretical sources. Therefore, some empirical information in this area was added as a complement, aiming to address this issue. However, theoretical science in this area should be stressed and future theoretical developments could reasonably contribute to additional understanding about distributed production at Volvo.

The results from this study could mainly be seen as of a conceptual nature, but more concrete and case-specific calculations and evaluations will be necessary, before being able to draw any reasonable general economic conclusions. The case study performed in this study is limited to contain only a few plastic spare parts, is lacking a cost perspective due to lack of sources, and is built upon several assumptions. However, the case study could contribute by serving as a simplified and illustrative example. There may be large opportunities for Volvo in the area of distributed production with the use of AM, but the company need to find ways of accessing resources and also perform further investigations in order to understand the application of distributed production with the use of AM in a broader perspective.

Furthermore, there are several areas not yet explored and several uncertainties which need to be critically evaluated. This study stresses the importance of considering the whole AM network, although this study mainly included the perspective of Volvo as well as AM service providers. Thus, the perspective of additional actors in an AM network could be an area for Volvo to investigate further, in order to capture industry trends, gain knowledge of capabilities and establish relationships to share competence, at an early stage.

There are several uncertainties related to the time perspective. The low availability on theory and case studies on distributed production indicate that this area is quite immature, but both the technology AM and the AM industry are developing rapidly. Hence it becomes difficult to foresee future capabilities related to AM and distributed production. In this study, the development historically and future expectations are included and used for the reasoning of opportunities and challenges with distributed production with the use of AM.

Currently, AM Experts from this study expect that AM itself will not replace traditional manufacturing methods but serve as a complement for production of low-volume parts. Furthermore, it was argued that there are many technical aspects with AM which need to be resolved in order for it to gain large-scale adoption across industries, and this development will differ depending on choice of material and the general development of the industry. However, since future development expectations are not solid, continuously updates are necessary, and it should be understood that the obsolesce of the findings from this study is impacted by these developments.

The future development of Volvo as a company also needs to be taken into account. Several opportunities and challenges are defined in this study. The development of the company Volvo and the service market division will impact on how to draw use of these opportunities and overcome mentioned challenges.

## 6.1 Strategy Moving Forward

As argued, there are significant possible opportunities and challenges related to distributed production of spare parts using AM. However, for Volvo to realize these opportunities the challenges and associated risks need to be mitigated. How these aspects relate to one-another is hence of significance, and from that being able to identify key areas to secure for Volvo when moving forward with AM and distributed production.

As a foundation for understanding the key aspects of Volvo's successful continued adoption of AM, the framework constructed by Mellor et al. (2014) and presented in section *2.1.5 Drivers for AM Adoption and Implementation* will be considered. The authors argue that the factors *AM Strategy*, *Technological Factors*, *Organizational Factors*, *Operation Systems*, *The AM Supply chain*, drive the adoption and implementation success of AM within firms, who are additionally impacted by *External Forces*. The presented challenges have been aimed to be categorized according to the framework with a consideration to distributed production, in order to determine the interrelation between them and how for Volvo to proceed in the area.

Firstly, a clear *AM Strategy* spans over all aspects of AM and distributed production, wherefore it is significant that it is clearly defined and that aims are communicated throughout the organization for continued AM adoption to be successful. This may especially be true for distributed production with AM, as decentralization would increase. This is in alignment with the arguments proposed by Mellor et al. (2014), who also argue that business model evaluation will become important in regards to this. The clarity in strategy and aim will aid in *Evaluating the Return on Investment*, as it can be determined whether the business cases for distributed production align with the overall strategy for

AM. This could hence mitigate the challenges discussed in section *5.3.6. Return on Investment.*

After a clear strategy has been formulated, understand the network interdependencies and risks are of importance for Volvo, to mitigate the challenges presented in section *5.3.1. Network Interdependencies and Risks*. This challenge spans over the framework, as the AM network may likely have an impact on Volvo's successful AM adoption. *Clarifying and Planning the Ownership and Information Management* in continued AM adoption and distributed production, to relieve challenges presented in section *5.3.2 Ownership and Information Management,* also spans across the framework. The same is true for reducing the barriers to adoption associated with section *5.3.3 Quality Management,* through *Improving Organizational Maturity*. This is an iterative and continuous process, which is gradually improved over time. For Volvo, it may be important to consider securing the areas and reaching an adequate maturity in the sections to the left of Figure 44, before making drastic changes in their supply chain.

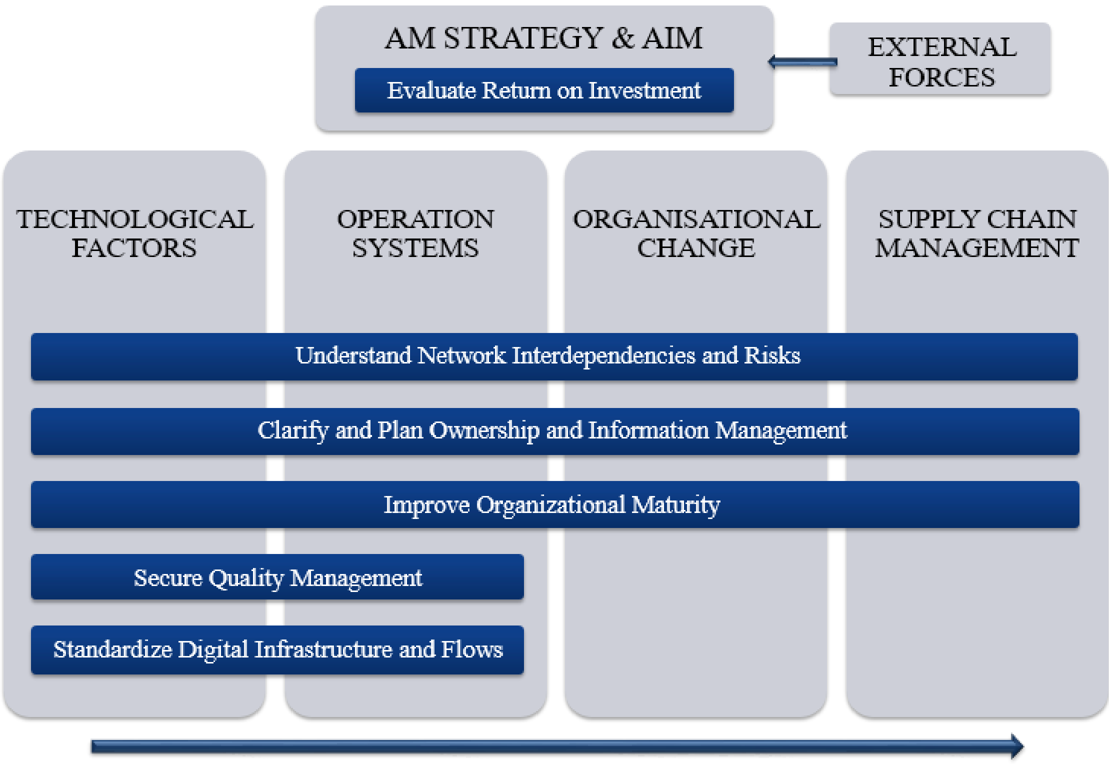


*Figure 44: Strategy for moving forward with AM and distributed production at Volvo*

*Securing Quality Management* and *Standardizing Digital Infrastructure and Flows* are furthermore key factors to AM adoption for Volvo, and in particular with distributed production. These are focused on the *Technological Factors,* but also span in to the *Operation Systems* as this is something that needs to be continuously improved and evaluated. This, in order to mitigate the challenges presented in sections *5.3.3 Quality Management* and *5.3.4 Digital Infrastructure and Copyright Infringement.* The development in all of the discussed areas are additionally influenced by external forces such as customer demand, regulations and pressure from competitors as discussed by Mellor et al. (2014).

# 7. Conclusion

This study has fulfilled the purpose of aiding the company Volvo Group in exploring and understanding the opportunities and challenges which distributed production using AM of spare parts would entail, and what impact it could have on the service market supply chain. This has been achieved through answering the research questions by comparing and contrasting theoretical findings and empirical data from internal and external sources.

The findings from the study concludes that the potential opportunities of distributed production of spare parts using AM for Volvo include: 1. Improved Supply Chain Reliability and Flexibility, as the distribution structure could be shortened through eliminating nodes, making the supply chain more agile. 2. Reduced Inventory Related Costs, as the need for central stock-keeping could be reduced. 3. Decreased Transports, as parts could be produced locally for the specific market. This could then minimize the current uncertainties and risks related to Volvo's long supply chain. 4. Reduced Lead Times, as production times, transports and handling could be reduced. 5. Increased Service Levels, as a greater variety of fewer products could be stocked economically or offered through print on demand. 6. Increased Customization Possibilities, as a decentralized structure could with the help of AM enable mass-customization.

The findings from the study further underline potential challenges of distributed production of spare parts using AM for Volvo's service market, which include: 1. Network Interdependencies and Risks, where it could be important for Volvo to understand and continuously monitor its position in the supply chain, choose a supply strategy carefully and follow market developments. 2. Ownership and Information Management, where it may be crucial for Volvo to establish clear governance structures internally and standardize information flows and assign ownership to the new flows of AM produced spare parts. 3. Quality Management, as there are significant technical limitations which currently present high barriers to AM and distributed production being viable, it is important for Volvo to understand the limitations and need for robust AM processes covering the entire AM network. 4. Digital Infrastructure and Copyright Infringement, where the 3D files of spare parts are crucial to secure and a common policy for data management and flows could be key. 5. Organizational Maturity, where it could be important for Volvo to increase AM acceptance through education and communicating pilot results throughout the organization, and hence easing the need for collaboration due to internal interdependencies. 5. Return on Investment, where using external AM partners could currently limit risk.

Despite AM being an enabler of distributed production, there are various critical strategic decisions for companies such as Volvo to take in terms of the level of distributed production and the interaction with actors in the AM network. The theoretical findings present a range of possible benefits of distributed production using AM for spare parts, but the challenges and risks found in both literature and in the empirical data are substantial and present significant barriers to adoption for Volvo.

Due to the rapid market development, there is a need for continuous re-evaluation of the possibility for distributed production using AM for spare parts, although there may currently be more urgent issues for Volvo to consider in terms of AM adoption. When moving forward with AM and potentially distributed production, the strategy for Volvo could be to manage the various challenges presented in a stepwise progression. Beginning with a clear and well communicated strategy could be essential, and after that moving on to securing the technical aspects and how organizational processes and information flows are handled, before making radical changes to the distribution structure.

A gradual and iterative process of increased AM maturity and understanding of the benefits, but most importantly of the limitations, of AM and distributed production are important in Volvo's continued AM adoption. Re-structuring the supply chain could hence be considered as a long-term goal in relation to AM, which is viable once the presented challenges can be sufficiently managed and the AM technology and supply market has gained increased maturity.

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# Appendix

## Appendix I

Table 11, Table 12 and Table 13 contain information extracted for the case study, including inventory levels, general information and transportation parameters for the respective 22 spare parts.

*Table 11: Inventory levels of each article from transportation from suppliers to dealers in Australia in pieces*

| Part | Supplier-CDC | CDC | CDC-RDC | RDC | RDC-Dealer | Dealer | Total Inventory |
|---|---|---|---|---|---|---|---|
| **A** | 2 | 764 | 0 | 993 | * | 58 | 1817 |
| **B** | 0 | 1215 | 0 | 125 | * | 45 | 1385 |
| **C** | 0 | 95 | 0 | 36 | * | 18 | 149 |
| **D** | 0 | 32 | 0 | 0 | * | - | 32 |
| **E** | 0 | 10 | 0 | 0 | * | 0 | 10 |
| **F** | 0 | 48 | 16 | 18 | * | 3 | 85 |
| **G** | 3 | 40 | 0 | 15 | * | 2 | 60 |
| **H** | 11 | 147 | 13 | 1 | * | 5 | 177 |
| **I** | 11 | 115 | 0 | 10 | * | 3 | 139 |
| **J** | 256 | 7339 | 0 | 57 | * | 12 | 7664 |
| **K** | 0 | 11 | 6 | 0 | * | 0 | 17 |
| **L** | 295 | 63 | 15 | 15 | * | 15 | 403 |
| **M** | 0 | 28 | 11 | 7 | * | 14 | 60 |
| **N** | 0 | 436 | 84 | 94 | * | 69 | 683 |
| **O** | 80 | 360 | 42 | 44 | * | 47 | 873 |
| **P** | 0 | 2743 | 512 | 337 | * | 203 | 3795 |
| **Q** | 0 | 1 | 0 | 19 | * | 8 | 28 |
| **R** | 0 | 3077 | 367 | 229 | * | 134 | 3807 |
| **S** | 0 | 26 | 5 | 5 | * | 6 | 42 |
| **T** | 0 | 34 | 5 | 7 | * | 8 | 54 |
| **U** | 0 | 36 | 0 | 9 | * | 10 | 55 |
| **V** | 0 | 8 | 0 | 12 | * | 10 | 30 |

*Table 12: Other data used for calculations in the case study*

| Part | Forecast in Gent [pieces/month] (Based on previous demand) | Forecast in Australia [pieces/month] (Based on previous demand) | Weight [g] | Location Supplier |
|---|---|---|---|---|
| **A** | 38,3 | 56,3 | 20 | Sweden |
| **B** | 115,5 | 3,1 | 33 | Sweden |
| **C** | 27,9 | 4,3 | 335 | Sweden |
| **D** | 0,4 | 0 | 362 | Netherlands |
| **E** | 0,0 | 0,2 | 6000 | France |
| **F** | 7,5 | 0,7 | 19 | Sweden |
| **G** | 0,9 | 0,4 | 148 | Sweden |
| **H** | 20,3 | 2,4 | 386 | Sweden |
| **I** | 15,4 | 1,9 | 385 | Sweden |
| **J** | 26,5 | 0,2 | 8 | Germany |
| **K** | 2,0 | 0,9 | 1950 | Norway |
| **L** | 21,0 | 4,4 | 52 | Sweden |
| **M** | 11,5 | 3,2 | 50 | Sweden |
| **N** | 358,8 | 22,4 | 34 | France |
| **O** | 416,9 | 9 | 37 | France |
| **P** | 2897,1 | 249,7 | 1709 | Italy |
| **Q** | 15,5 | 0,7 | 545 | Italy |
| **R** | 2856,9 | 170 | 1183 | Italy |
| **S** | 15,2 | 0,8 | 495 | Sweden |
| **T** | 18,5 | 1,1 | 492 | Sweden |
| **U** | 19,2 | 0,8 | 495 | Sweden |
| **V** | 12,8 | 0,9 | 455 | Sweden |

*Table 13: Transport parameters for the supply chain flow of the parts in the case study expressed in KM-KG, for one part*

| Part | KG-KM to CDC | KM-KG to RDC (Sea) | KM-KG to RDC (Air) | KM-KG to Dealer | TOT KG-KM Sea | TOT KG-KM Air |
|---|---|---|---|---|---|---|
| A | 23,02 | 428 | 334,18 | 38,68 | 490 | 396 |
| B | 37,983 | 706,2 | 551,397 | 63,822 | 808 | 653 |
| C | 385,585 | 7169 | 5597,515 | 647,89 | 8202 | 6631 |
| D | 24,616 | 7746,8 | 6048,658 | 700,108 | 8472 | 6773 |
| E | 3420 | 128400 | 100254 | 11604 | 143424 | 115278 |
| F | 29,659 | 406,6 | 317,471 | 36,746 | 473 | 384 |
| G | 231,028 | 3167,2 | 2472,932 | 286,232 | 3684 | 2990 |
| H | 514,538 | 8260,4 | 6449,674 | 746,524 | 9521 | 7711 |
| I | 513,205 | 8239 | 6432,965 | 744,59 | 9497 | 7691 |
| J | 2,368 | 171,2 | 133,672 | 15,472 | 189 | 152 |
| K | 2940,6 | 41730 | 32582,55 | 3771,3 | 48442 | 39294 |
| L | 67,028 | 1112,8 | 868,868 | 100,568 | 1280 | 1036 |
| M | 64,45 | 1070 | 835,45 | 96,7 | 1231 | 997 |
| N | 10,982 | 727,6 | 568,106 | 65,756 | 804 | 645 |
| O | 11,951 | 791,8 | 618,233 | 71,558 | 875 | 702 |
| P | 1796,159 | 36572,6 | 28555,68 | 3305,206 | 41674 | 33657 |
| Q | 584,785 | 11663 | 9106,405 | 1054,03 | 13302 | 10745 |
| R | 1243,333 | 25316,2 | 19766,75 | 2287,922 | 28847 | 23298 |
| S | 757,35 | 10593 | 8270,955 | 957,33 | 12308 | 9986 |
| T | 752,76 | 10528,8 | 8220,828 | 951,528 | 12233 | 9925 |
| U | 757,35 | 10593 | 8270,955 | 957,33 | 12308 | 9986 |
| V | 696,15 | 9737 | 7602,595 | 879,97 | 11313 | 9179 |

## Appendix II

This appendix contains the interview guides which were used during the empirical data collection of the study, including internal and external interviews as well as the correspondence with AM service providers.

### Interview Guide for Internal SML Department Representatives

1. Could you please shortly describe your department and your role within it?
2. What are the main objectives of your department?
3. What are the main responsibilities of your department?
4. What regions do you operate in and which spare parts do you handle?
5. What are currently the main challenges facing your department?

### Interview Guide for Senior Purchasing Manager

1. Could you please shortly describe the current state of the AM supplier base?
    a. Will these be used for all AM needs or a specific category (e.g. prototyping, spare parts, BOR etc.)?
    b. Will certain suppliers cover specific regions and categories?
    c. When do you expect to be finished with the supplier base evaluation process?
2. How/Why did you choose these suppliers?
    a. Based on regular processes or were exceptions made?
    b. When/if geography is considered, what is the optimal location of the supplier?
3. Does purchasing consider logistics cost in the part price?
4. Do you see these relationships developing more in to partnerships where they can be a part of a 3D drawing creation and even help with part selection?
5. How are these AM spare parts planned to be distributed in the supply chain? Through CDC and then RDC and SDC?
6. Do you believe there will be a capacity issue at the suppliers due to the rapid growth of the technology?
7. What is your perception of various alternatives of distributed production using AM?

## Interview Guide for External AM Experts

1. Could you please tell us a little bit about yourself and your background within AM?
2. What challenges and opportunities do you see for producing spare parts with AM in different geographical places or through different suppliers closer to the customer (Distributed Production)?
    a. What do you believe are key aspects of enabling this?
3. Have you come in contact with any company who work with distributed production using AM?
4. Do you believe the future of AM will be more or less decentralized?
5. What do the technological developments within AM look like?
    a. Cost developments
    b. Printer Speed
    c. Post-processing
    d. Advanced printers
6. How much AM knowledge or competence is required to use a machine which can produce industrially quality assured parts?

## Questions to AM Service Providers

1. In how many different locations do you currently print?
    a. Are the sites specialized in different techniques/materials?
2. What are the typical volumes requested by customers?
    a. How (if) do you handle packing and shipping of small quantities/single part?
3. How is the current quality assurance process performed?
4. To what extent can customers monitor the printing/quality assurance processes?
5. Are you currently working with customers where you print the same products at different locations?
    a. Do you see any obstacles with this way of working?
6. How do you ensure the same quality and product capabilities across different geographies?
7. In the future of AM, do you see a more dispersed or centralized form?
    a. Why, why not? Time horizon?
    b. What will be the main drivers for this?
    c. How could quality assurance be performed?