Using 3D-Printing for Improving Backorder Recovery

A study performed at Volvo Group

Master's thesis in Supply Chain Management

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Abstract

Purpose – Fast backorder recovery for spare parts is crucial for customer satisfaction but is sometimes slow due to sourcing or tooling issues, long production- or waiting time. 3D-printing has the potential to complement and improve Volvo's current backorder recovery process. Therefore, the purpose of the thesis is to assess the possibility to use 3D-printing for backorder recovery where it is beneficial in terms of cost, lead time and environmental impact.

Scope - The expected outcome is to provide a recommendation of direction of how 3D-printing can be used as complement in Volvo's backorder recovery process. The recommendation is of a conceptual nature of how 3D-printing can become a part of the Volvo's way of working with backorders. The proposal includes what can be achieved today and in five to ten years if the rapid development of 3D-printing technologies continues. The thesis has a logistics focus and the scope is to see when and how 3D-printing can be used in order to improve backorder recovery, i.e. it is not used how backorders can be avoided.

Methodology – The thesis is of qualitative nature, where the empirical findings are compared to relevant literature in order to answer the research questions. To get a reliable result both first and secondary data has been collected. The data was analyzed in order to provide a future recommendation for in what direction the company should go in the investigated area. Additionally, a case study was performed to illustrate an actual case and to see if the analyzed parameters affected the chosen measurements.

Results – One precondition today is long time backorders due to the lead time of 3D-printing. The case study result shows that today lead time can be shortened for these backorders, but at the expense of increased cost. However, the application has been noticed to be very case dependent and therefore difficult to generalize. Today's major limitations, which are lack of quality assurance, lead time and product printability, are however believed to diminish in the future and increase the potential further for backorder recovery.

Conclusion – The conclusion from the investigation is that backorder recovery is an area with high potential for using 3D-printing. Even if today 3D-printing as a technology is not quite mature to apply in the backorder recovery process.

Keywords: 3D-Printing, Backorder Recovery, Automotive Industry, Spare Part Distribution

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Abbreviations

3DP - 3D-printing
AM - Additive manufacturing
BO - Backorder
BOR - Backorder recovery
CAD - Computer aided design
CDC - Central distribution center
DC - Distribution center
EBM - Electron beam melting
ETA - Estimated time of arrival
IP - Intellectual property
RDC - Regional distribution center
SC - Supply chain
SDC - Support distribution center
VCE - Volvo Construction Equipment
VOR - Vehicle off road

1. Introduction

3D-printing (3DP) has received great attention the last couple of years and has been regarded as a disruptive technology revolutionizing product development and manufacturing (Gibson, Rosen & Stucker, 2015). Due to the progress in the technique and attention for a wider future area of use, Volvo has previously investigated the use of 3DP in the aftermarket. A study performed during 2015 investigated if 3DP could lower the inventory cost for low turnover parts but still keep the same availability. The findings were that cost could be lowered for some parts (about six to twenty percent). However, the biggest finding was that lead time could be reduced significantly. Therefore, Volvo wants to investigate the use of 3DP as a complement in the backorder recovery (BOR) process as well, where lead time is of high importance due to its effect on customer satisfaction.

Volvo defines a backorder (BO) as an order for a part that cannot be filled at the current time due to a lack of available supply. BO is a status of an order and is defined by no instant availability in the storage shelves locations (i.e. no stock of the right part number, right brand, right packaging etc.). Due to the high importance of fast BOR for customer satisfaction Volvo wants to improve this process. In some cases, the waiting time for the customer to receive the ordered product can be up to one year and the product might not even be possible to deliver at all due to different causes.

Except for the possibilities to decrease cost and lead time, 3DP has more benefits and can have great impact on the supply chain. One possible advantage is the resource efficiency, since in some cases it can be less resource consuming in the manufacturing phase, due to less scrap and material use. In addition, the freedom of design and the increased postponement possibility reduces the risk of overproduction and obsolescence (Mohr & Khan, 2015). Furthermore, 3DP can contribute to shorter transportation distances (Mohr & Khan, 2015) which contributes to lowering the emissions caused by transportation. The possibilities derived from the result of this thesis show a reduction in both lead time and environmental impact which is in line with the company's vision of being a world leader in sustainable transport solutions. A target set for the company is to lower the carbon dioxide emissions per produced unit from the Volvo Group freight transport by 2020 with 20% (WWF, 2014). Volvo believes that the use of 3DP is a possible choice for some backordered spare parts. This thesis aims to answer the questions about when, how and where it will be beneficial.

1.2 Purpose

Fast BOR is crucial for customer satisfaction but is sometimes slow due to sourcing or tooling issues, long production- or waiting time. Additionally, minimum order quantities can generate obsolescence and high inventory costs which have a negative impact on the business. 3D-printing has the potential to complement and improve Volvo's current backorder recovery process. Therefore, the purpose of the thesis is to assess the possibility to use 3DP for BOR where it is beneficial in terms of cost, lead time and environmental impact.

1.2.1 Research questions

The following research questions aim to be answered in order to fulfill the purpose of the thesis:

In order to be able to analyze the current situation and see possibilities for an alternative solution to the BOR process it is important to know how the process works today. It is also important since the performance of the current process will be compared to the recommended solution. Further, it is important to be able to relate the alternative solution to the circumstances that might affect the future scenario. Since this will provide insight to where and when in the process the solution can be used to highest potential. Therefore, the first research question is:

- *In what context does 3DP, as a manufacturing technique (spare part provider), need to operate and in what situations can it be used to its highest potential for BOR?*

Since Volvo has not previously worked with 3DP in the BOR process or in the aftermarket it is important to see where the technique can be used. All products are not possible to produce using this technique which results in constraints. Feasibility is another important aspect when it comes to introducing 3DP in the process since otherwise there is no incentive for the company to change the process. There are several aspects that are important to take into account when evaluating how 3DP affect BOR. The most important ones that also are possible to investigate have been identified as cost, lead time and environmental impact. Lead time is the time between registered BO until it is recovered in the system. Cost includes the different costs that can be derived to the BO and the environmental impact is limited to the CO_2 emission for the transportation of the BO. However, it is important to be aware of that there are several other aspects that also are affected and are interdependent. Even so, these measurements are deemed suitable for providing a limited proof of feasibility and based on this the second research question is:

- *How can 3DP affect the current BOR process at Volvo in terms of lead time, cost and environmental impact?*

3DP is a production technique with high potential and has received a lot of attention during the last years (Gibson, Rosen & Stucker, 2015). The technique is continuously evolving and new applications and areas of use are found, even if it also connected to challenges. As it is today, Volvo is not using the technique in the BOR process, but has an interest in introducing it to achieve all the benefits it might bring. Since the advances in 3DP is believed to increase during the next years (Gartner, b, 2015; Giffi, Gangula & Illinda, 2014; Mohr & Kahn, 2015; Sasson & Johnson, 2016; Srivatsan & Sudarshan, 2016) it is important for to address the progress and trends in the area of 3DP. The third research question consider a time span of five to ten years. The future aspect is further important since the introduction of 3DP is considered as an important project with future potential but needs more knowledge and research before an implementation. The time span has been requested by Volvo.

- *How can 3DP affect BOR process at Volvo in five to ten years in terms of lead time, cost and environmental impact?*

1.3 Scope

This thesis has a logistics focus and investigates how 3DP can be used in the BOR process in the aftermarket at Volvo. Focus will not be on the 3DP technology itself and how it works. A short background and description of the technology will be included, but focus is on how the technology can be applied in a logistics setting. The scope is to see when and how 3DP can be used in order to improve BOR, i.e. it is not used to see how the BOs can be avoided.

1.3.1 Delimitations

The product aspect of which spare parts can be produced using 3DP will be briefly covered. This since the main focus is on the process which also includes the products, but no major investigation of the products will be done. This means that if a specific product is printable or not will not steer the result. The thesis will neither cover an implementation plan of the suggested improvements of the BOR process.

1.4 Expected Outcome

The expected outcome is to provide a recommendation of direction of how 3DP can be used as complement in Volvo's BOR process. The recommendation is of a conceptual nature of how 3DP can become a part of the Volvo's way of working with BOs. The proposal includes what can be achieved today and in five to ten years if the rapid development of 3DP technologies continues.

Furthermore, to back up the suggestion a limited proof of a positive result is provided, in which the current process is compared to the suggested future state in order to see improvements. This limited proof is supposed to be regarding some groups or parts of the process.

2. Theoretical Framework

This section contains the theoretical framework used for the thesis work. The framework was chosen in order to provide an understanding about the investigated topics. This includes both 3DP as a technology and the automotive aftermarket and its characteristics. More specifically, the chapter consists of 3DP, spare part distribution, automotive aftermarket, supply chain challenges customer service and BOs.

2.1 3D-Printing

Additive manufacturing (AM) is a technique which in contrast to traditional manufacturing techniques adds material to build up the product instead of removing excess material (Srivatsan & Sudarshan, 2016; Gibson, Rosen & Stucker, 2015). AM can be defined as "*as the process of joining or adding materials with the primary objective of making objects from three-dimensional (3D) model data using the layer-by-layer principle"* (Srivatsan & Sudarshan, p. 4, 2016).

AM is also known as 3DP, a term which is more commonly used lately (Gibson, Rosen & Stucker, 2015). 3DP and AM are normally used synonymously, which also is the case in this report. The term 3DP originated from Massachusetts Institute of Technology that patented three-dimensional printing (Srivatsan & Sudarshan, 2016; Gibson, Rosen & Stucker, 2015). It is believed that the term 3DP has gained popularity due to that the term can be related to traditional two dimensional printing, to which people easily can relate (Gibson, Rosen & Stucker, 2015).

The origin of 3DP can be difficult to define since there have been several patents describing the similar manufacturing technique, adding material layer by layer. Initial research can be found as early as the 1950's to1960's, however the technique that is connected to 3DP today was patented in the 1980's (Gibson, Rosen & Stucker, 2015). The patents were filed in several parts of the world, however, the one that is seen to have had the biggest impact on 3DP is the one filed by Charles Hull in USA in 1984. This patent later gave rise to the company '3D-Systems' which was the first one to commercialize the technology (Gibson, Rosen & Stucker, 2015).

After the first patents expired in early 2010, there have been explosions of vendors and systems which have resulted in several companies on the market. Most successful 3DP companies have been developed in USA. Companies such as 3D Systems, Stratasys and ZCORP has led the way forward in the development of the technology and strengthened their position over the years. The recent trend is however that new 3DP companies from outside of the US are increasing and are increasingly successful in their markets (Gibson, Rosen & Stucker, 2015). However, USA is still today the country who leads the world in 3D printing innovation and adoption (Frost & Sullivan, 2015).

To produce an object using 3DP a Computer-Aided Design (CAD) drawing is required, from which the object is created. Layer by layer powder is glued together using a binder and gradually the product is built up. When adding material to build up the product, 3DP generate less waste. Excess powder can often be reused and the technique is therefore considered to have high efficiency in material use (Srivatsan & Sudarshan, 2016). There are several methods used in 3DP. There are different processes on the market such as power bed fusion processes, extrusion-based systems and photo polymerization processes (Gibson, Rosen & Stucker, 2015). The development of materials that are possible to print has progressed during the last years to over 100 different materials and today it is possible to print materials such as plastics, ceramics and metal materials. With 3DP it is possible to produce complex geometric shapes. 3DP gives the freedom to optimize the design of the product as well as the opportunity to customize products according to customers wishes (Srivatsan & Sudarshan, 2016).

Faster product development process is an advantage highlighted by Gibson, Rosen and Stucker (2015). Another advantage with 3DP is that the product can be produced in a single machine and replace a number of production steps compared to using traditional manufacturing techniques (Gibson, Rosen & Stucker, 2015; Srivatsan & Sudarshan, 2016). According to Srivatsan and Sudarshan (2016), 3DP contributes to efficiency in the use of resources such as fixtures, cutting tools, coolants etc. since they can be replaced by a 3DP machine.

Srivatsan & Sudarshan (2016) states:

"...additive manufacturing does not require such additional resources. As a result, a variety of parts can be made by small manufacturers that are located close to their customers. This scenario presents an opportunity for improved supply-chain dynamics." (Srivatsan & Sudarshan, p.25, 2016)

Other authors such as Sasson and Johnson (2016) also mention the impacts 3DP can have on the supply chain:

"Local or regional 3D printing will reduce finished good delivery time, mitigating safety stock requirements" (Sasson & Johnson, p.86, 2016).

Furthermore, Srivatsan and Sudarshan (2016) say that AM impact the supply chain through decreasing the time to market and that it can be used in a just-in-time setting. This is supported by Sasson and Johnson (2016) who says that 3D printing as a technique is preferably used in settings where an urgent product that interferes with the normal production is needed. For example, it can be for sporadic and low demand products that require setup time in the manufacturing.

3DP has received a lot of attention and the aforementioned benefits which 3DP can bring are often highlighted. However, there are also drawbacks with 3DP. For example, it is not possible to use 3DP for all materials. Together with uncertainties regarding product properties the limited materials that can be processed by 3DP is hindering usage of the technology (Babu & Goodridge, 2015). Another drawback with 3DP is that there are limitations regarding size of the objects that can be produced. Furthermore, the technique gives the surface of the produced object a rather rough and unfinished look, which might require polishing or additional processing (Srivatsan & Sudarshan, 2016). The cost of investing in the 3DP equipment is also high and according to Srivatsan and Sudarshan (2016). However, when the investment is made the main costs impacting the price for 3D-printed metal products are according to Shapeways (2016) labor and material costs. For plastic parts, the price also often is dependent on how much space that are used in the 3DP machine, since it is possible to print several products assuming that there is enough space (ibid).

The top 3DP suppliers on the market today are Stratasys, 3D-systems, Materialise, ExOne and Arcam (3D Printing Industry, 2015). 3DP has made progress in foremost the aerospace industry and for biomedical applications (Babu et al., 2015). For example, one of the leading suppliers, Arcam, specializes in titanium products using the EBM (electron beam melting) technique. Arcam focuses on the aerospace products and orthopedic implants. The EBM technique is especially beneficial in the aerospace industry due to the importance of weight reduction, which is one of the characteristics of the finished products using this technique (Arcam, 2016).

Even if 3DP is not mainly developed for automotive industry there are still areas within the industry where it is used. In 2015 the use of 3DP was 90% for prototyping and 10% for production (Frost & Sullivan, 2016). 3DP has also been used successfully in the automotive industry in producing tools. According to Stratasys Ltd. (2015) the automotive company Opel managed to cut tooling cost with 90% using 3DP. Additionally, the time to produce the tools is reduced significantly while the design freedom is increased.

Today the technique is restricted to producing extremely low volume parts and production tooling (Frost & Sullivan, 2016). One of the main limitations for 3DP is the speed and size of the production technique. Even due to these limitations the impact on the aerospace and biomedical industry has been large (Babu et al., 2015). However, it limits the possibilities in other industries, such as the automotive industry. A technique that aims to deal with these limitations is the BAAM (big area additive manufacturing) methodology that can create large object fast. By using this method of 3DP entire vehicles has been produced, one of them called the "Strati". The Strati was manufactured in 48 hours' time and consists of ~50 parts (Babu et al., 2015; Komenda, 2014). In comparison to a traditional car that uses around 20.000 parts this is a huge reduction which reduces both complexity and weight (Babu et al, 2015).

Giffi, Gangula and Illinda (2014) use Cotteleer and Joyce's (2014) framework for understanding AM paths and values (see Figure 1) to describe the current use of AM in the automotive industry. The framework is based on the understanding of how AM technologies can break the trade-offs between capital and economies of scope and scale (Giffi, Gangula & Illinda, 2014). According to Giffi, Gangula and Illinda (p.5, 2014), *"the flexibility of AM facilitates an increase in the variety of products a unit of capital can produce, reducing the costs associated with production changeovers and customization and/or the overall amount of capital required"* and that *"AM has the potential to reduce the capital required to reach minimum efficient scale for production, thus lowering the barriers to entry to manufacturing for a given location".*

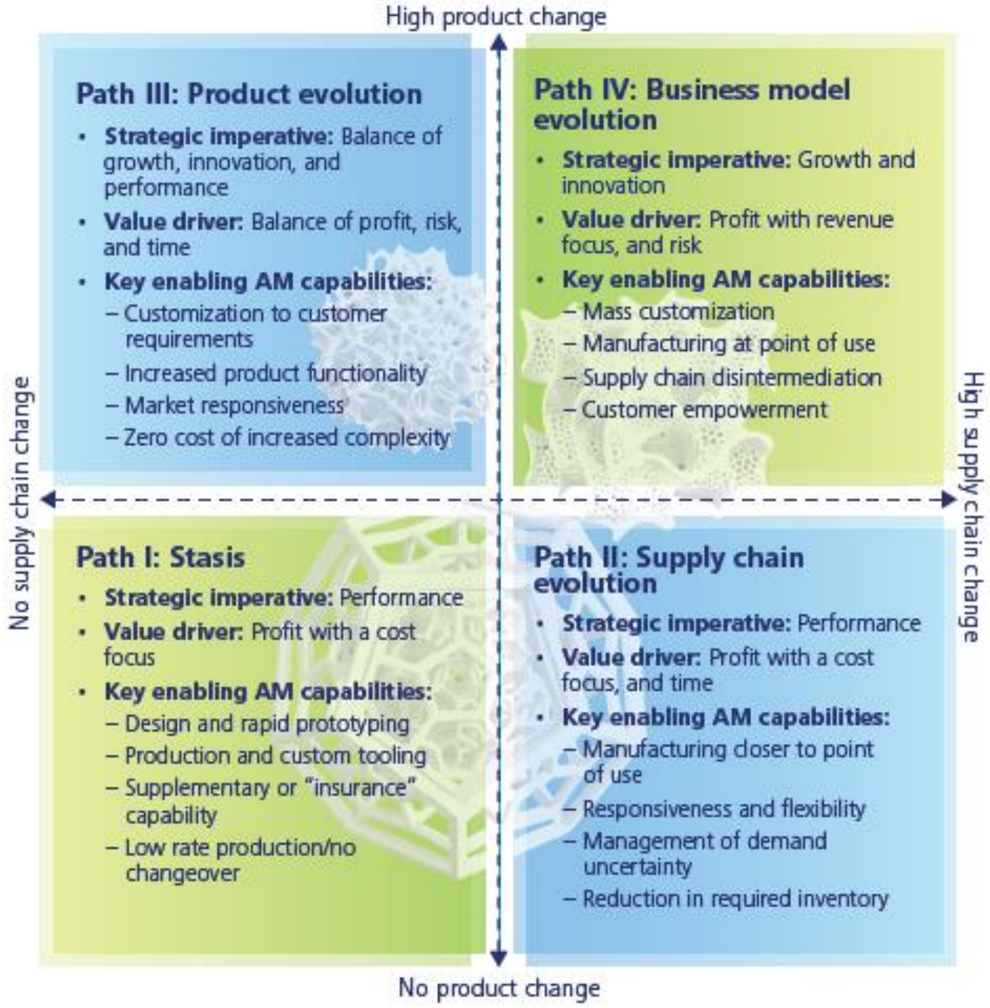

Figure 1: Framework for understanding AM paths and values (Cotteleer & Joyce, 2014)

In the framework four tactical paths are identified. In 2014, most OEMs and suppliers in the automotive industry were exploring the AM technologies and were situated in the bottom left square in Figure 1. The companies in this square use AM to improve current operations rather than performing radical changes in their products and supply chains (Giffi, Gangula & Illinda, 2014). According to Giffi, Gangula and Illinda (2014), the path where OEMs can gain long term advantages in the automotive industry is Path IV. In this path companies should develop how they use AM today and create new business models for AM. Focus should be on product innovation and advancement together with developing supply chains that are suited for the new business models.

Giffi, Gangula and Illinda (2014) say that AM can shorten and simplify the automotive supply chains and that OEMs thereby can reduce supplier involvement and spend less time on sourcing when printing their own parts. To use AM in the automotive supply chain can lower the cost of inventory and reduce the lead time for repairing vehicles. In the automotive industry, parts availability and delivery time are important in order to be competitive in the aftermarket. For expensive and long-tail components that usually are not stored at the dealers but placed further away from the customer, the use of 3DP can help to balance the demand

and supply with on-demand production (Giffi, Gangula & Illinda, 2014). Giffi, Gangula and Illinda (p.12, 2014) describe long-tail components as *"parts that are in demand but only in small volumes"*. Another application for AM in the automotive supply chain identified by Giffi, Gangula and Illinda (2014) is to repair parts at service locations. This is especially relevant for expensive parts that are costly to replace.

Regarding product innovations and advances, in the automotive industry there is a concern regarding intellectual property (IP). Copyright does not apply for AM products, but can instead be patented. However, there are no clear rules for the patent protection, which means that there is a risk for counterfeit parts entering the automotive aftermarket. This is enabled due to theft of IP and result in financial loss for the OEM (Giffi, Gangula & Illinda, 2014).

2.1.1 Trends and Predicted Future

"Emerging technologies" is a term for new, developing technologies that have the possibly to significantly affect social environment and business models (Vong & Song, 2015). Gartner is a company that has been following progress of emerging technologies the last two decades. The company has yearly published what they call Hype Cycles, in which maturity of emerging technologies are presented. 3DP entered the Hype Cycle in 2007 and the expected time to mainstream adoption was then predicted to be five to ten years (see Figure 2) (Gartner, 2014).

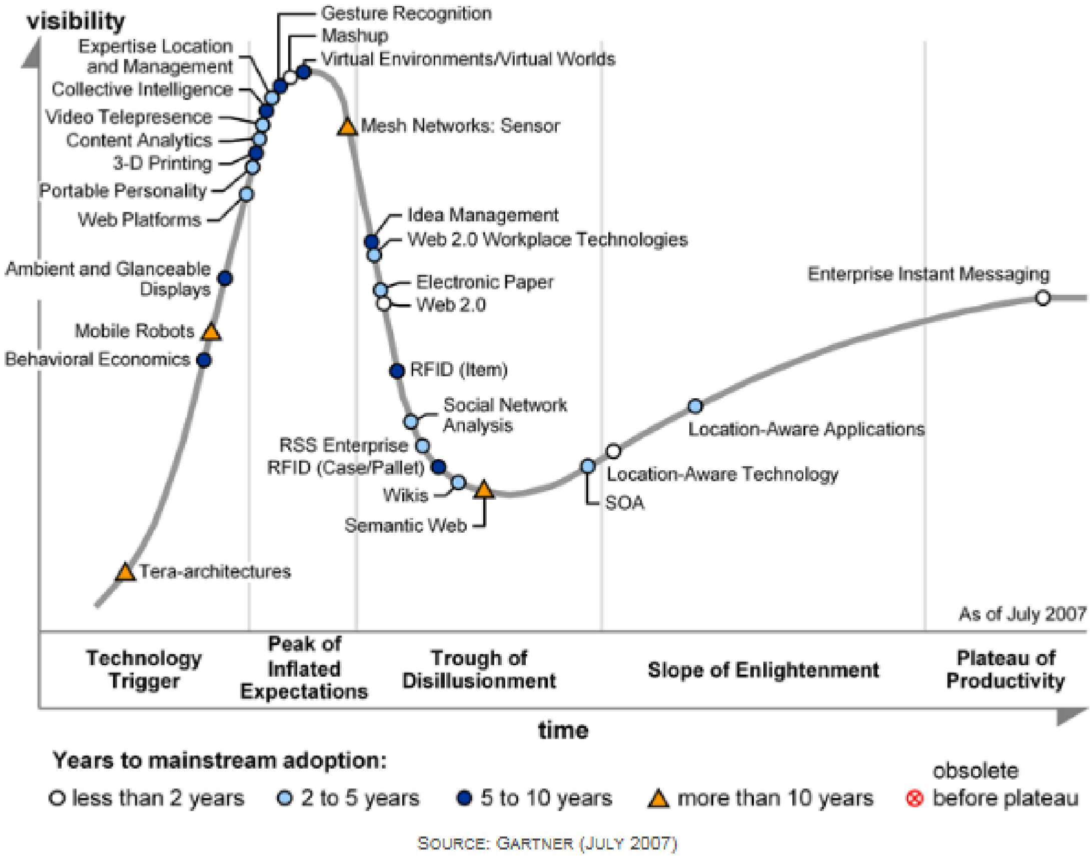

Figure 2: Hype Cycle for emerging technologies, July 2007 (Gartner, 2014)

It took several years for the technology to reach the peak of inflated expectations. It finally did in 2012 and in 2014 3DP was located in the slope of enlightenment. Then the estimated time for reaching the plateau of productivity was believed to be two to five years (see Figure 3).

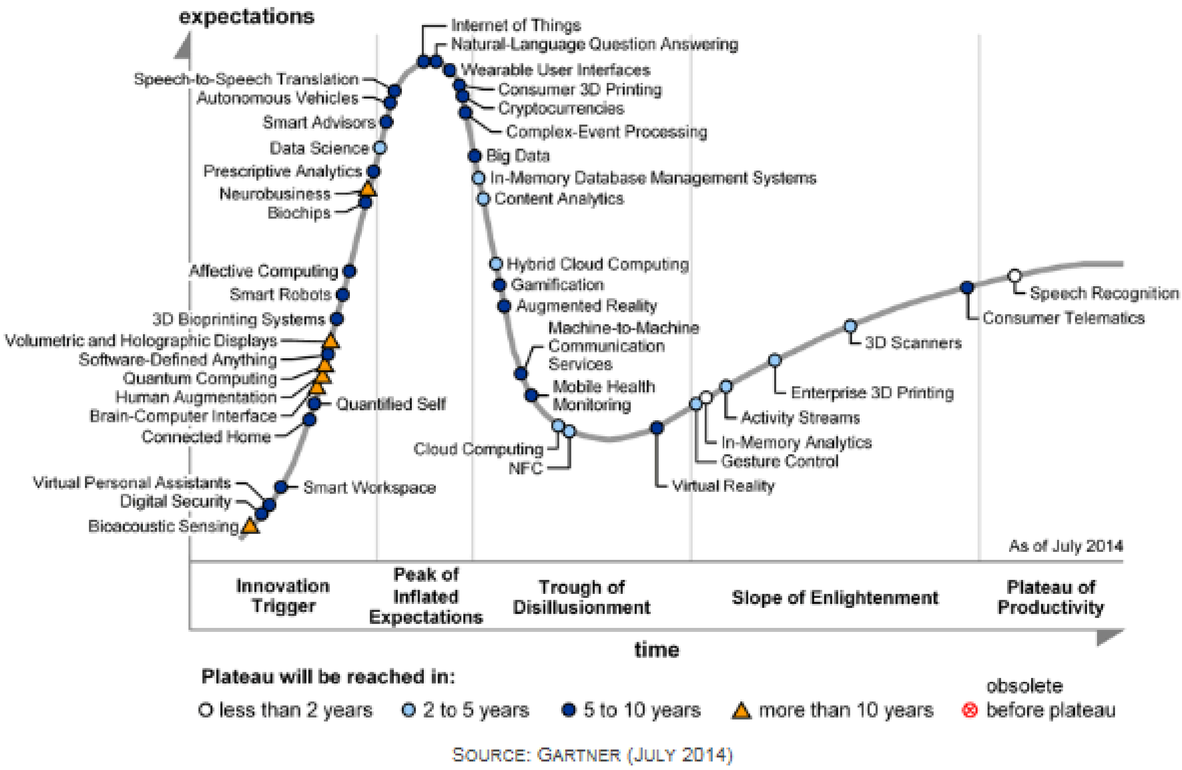

Figure 3: Hype Cycle for emerging technologies, July 2014 (Gartner, 2014)

When an emerging technology progresses it often does not move along the Hype Cycle in a smooth and predictable way, but rather takes sudden jumps. It is therefore important to keep updated and continuously stay informed of the latest progress. For companies to be prepared for sudden progress in the technology, it is recommended to have collaboration with vendors of the technology in order to gain valuable insights and information (Gartner, 2014).

The expected progress of a technology can be delayed due to several reasons. One reason identified is that integration with existing technology and between business functions might be needed. In order to achieve this, cooperation across various work areas could be needed and this prolongs the time until the technology can be commercialized. Furthermore, companies must realize the benefits of the new technology which require efforts and resources. This takes time from the daily work and together with resistance from society it can result in longer time for the technology to be commercialized. Another reason is that even though the technology is functionally working, it can be hard to find an area of use where it is sufficiently profitable (Gartner, 2014).

3DP was one of the top ten strategic technology trends for 2015 listed by Gartner (a, 2015). Gartner evaluates the trends using a technology adoption cycle that takes time and growth in account. 3DP was then approaching a critical inflection point and entering the mainstream part of the graph in Figure 4.

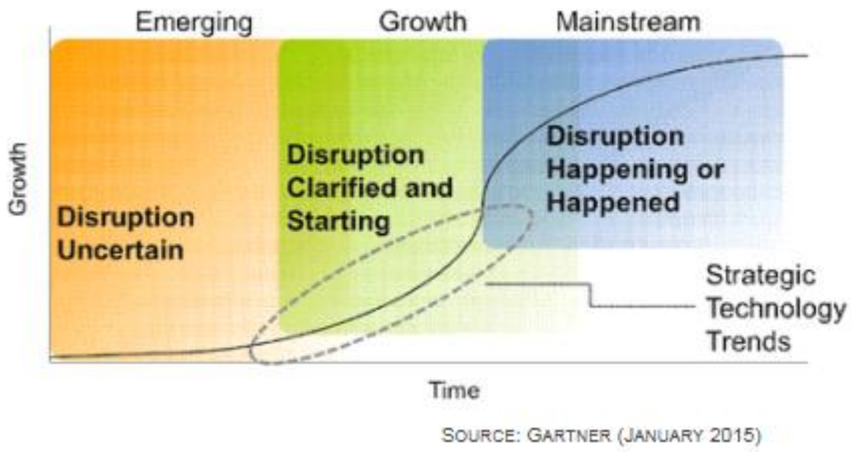

Figure 4: The technology adoption cycle (Gartner, a, 2015)

When approaching 2016 Gartner (b, 2015) still considered 3DP as one of the top ten technology trends for the upcoming year. Advances in the technology have made it possible to find more practical applications in more sectors, among them the automotive industry. According to Gartner (b, 2015) *"new supply chain processes that exploit opportunities for 3D printing on demand, and assembly line processes that can embed components within 3D-printed materials, will create business disruption"*. Furthermore, "*the growing range of 3D-printable materials will drive a compound annual growth rate of 64.1% for enterprise 3D-printer shipments through 2019"* (Gartner, b, 2015).

According to Manners-Bell (chapter 15, 2014) 3DP, "*has the potential to become the biggest single disruptive phenomenon to impact industry since assembly lines were introduced in early 20th-century America*". The authors Mohr and Khan (2015) also stress the impact 3D-technology will have on the industry in the future. They identify seven key areas that are probable to be affected by the developing 3DP technology, these are:

1. Mass customization
2. Resource efficiency
3. Decentralization of manufacturing
4. Complexity reduction
5. Rationalization of inventory and logistics
6. Product design and prototyping
7. Legal and security concerns

These areas are affected by certain aspects regarding the 3D-technique and what it might bring to the supply chain. For example, the possibilities for closer connection to the end market and customer result in decentralization of the manufacturing which in its turn reduce the environmental impact and reduces the inventory levels. The complexity reduction is driven by that fewer components are required for the product since entire parts can be produced that normally would have to be assembled. Product design and prototyping are further impacted by the freedom of design. Since product do not need to be adapted to certain manufacturing techniques. Finally, 3DP enables postponement and customization since it can be produced closer to the customer and with a higher degree of design freedom (Mohr & Khan, 2015).

Frost and Sullivan (2016) predict that by 2025 3DP will generate 4.3 billion dollars and increase the impact especially in the production and the aftermarket. The increased use will be mainly due to the reduced material and production cost in the technique. In the future the costs for 3D-printers are expected to decrease and this is considered as an important driver of 3DP in the automotive industry. Further drivers are expiring patents, more time and cost efficient product development and innovations for material that can be used for 3DP (NewsRx LLC, 2015).

2.2 Spare Part Distribution and Materials Management

Logistics is an important activity and is necessary in order to provide the resources to different parts of the supply chain. According to Rushton, Croucher & Baker (2014) logistics stands for as much as 11% of the gross domestic product in the North American, European and the Asia Pacific economies. For the largest economies in the world the logistics stands for between 8-21% where the developing countries have a higher percentage, between 12-21%. It is therefore of highest important for companies today to keep the logistics cost to a minimum.

The total cost of the distribution system consists of several different areas. Costs that can be derived to the logistic activities are so called logistics costs. These can, according to Jonsson and Mattsson (2011), be broken down into the following categories; transportation and handling, packaging, inventory management, administrative, order handling, capacity and stock out/delay costs. Logistics is regarded as a system, where decisions regarding certain costs affect other parts of the system. According to Christopher (2010), the traditional way of accounting is by grouping cost into aggregated categories which is not suited for identifying the true cost for a distribution system, since it is originally developed for products. This way of accounting makes it difficult to assess the performance of the logistics system in an accurate way. The largest costs associated with the logistics is however, according to Establish/Herbert Davis' (2011) survey; transportation at 49%, warehousing at 23%, inventory carrying costs at 22%, customer service/order entry at 4% and administration at 2% (Rushton, Croucher & Baker, 2014). The transportation costs are affected by high fuel price and distances. The long distances are especially an issue in the US (ibid).

To solve issues in the distribution, the structure can be altered. However, changing the structure is often connected to costs. For example, when removing or adding a depot in the distribution system the affected costs are, according to Christopher (2010) inventory costs, trunking costs, outlet costs, local delivery costs and order processing costs. When increasing the number of facilities, the inventory and facility costs increase, however less transportation is needed and therefore result in lower transportation costs (Chopra & Meindl, 2013; Jonsson & Mattsson, 2011). This is true as long as the number of facilities do not reduce the economies of scale, since this increase the transportation costs (Chopra & Meindl, 2013).

Another important area of businesses is materials management. According to Vrat (2014) there are three main reasons behind why materials management should have high priority in enterprises today. Firstly, material related costs stand for a large part of businesses total costs, and therefore the potential for savings in this area is significant. The second reason is regarding the importance of the material for different parts of the business, it is an input to production as well as service systems and the availability and quality of the material are a precondition for effective processes. The final reason mentioned by Vrat (2014) is due to globalization. A coordinated material flow is becoming even more important in order to handle presence on a global market.

There are several costs connected with materials management. These costs can for example be inventory carrying costs, shortage costs or cost of materials handling (Vrat, 2014). High inventory levels increase the tied up capital as well as the handling and storage of material. Reasons behind excess inventory can be uncertain demand, long procurement lead times or high variety of parts (Vrat, 2014). Uncertain demand and a high variety of parts are closely linked to the distribution of spare parts.

Spare parts are an important part of maintenance, which according to Van Houtum and Kranenburg (2015) can stand for a large part of the total cost of ownership when investing in new systems. Maintenance can be either preventive or corrective. The preventive maintenance is scheduled in advanced while the corrective maintenance is required due to system failure (ibid). The corrective maintenance, which is the focus of this thesis, often requires spare parts since breakdowns can occur due to faulty parts. Since breakdowns cannot be scheduled, this requires that spare parts are kept in inventory to be able to reduce costly downtime (ibid). Increased need for inventory due to uncertainty in demand is also supported by Vrat (2014).

The main objective of a spare part distribution network is to deliver spare parts within a specific time frame (Van Houtum & Kranenburg, 2015). A typical network consists of suppliers, central warehouses and local warehouses. The network is described in Figure 5.

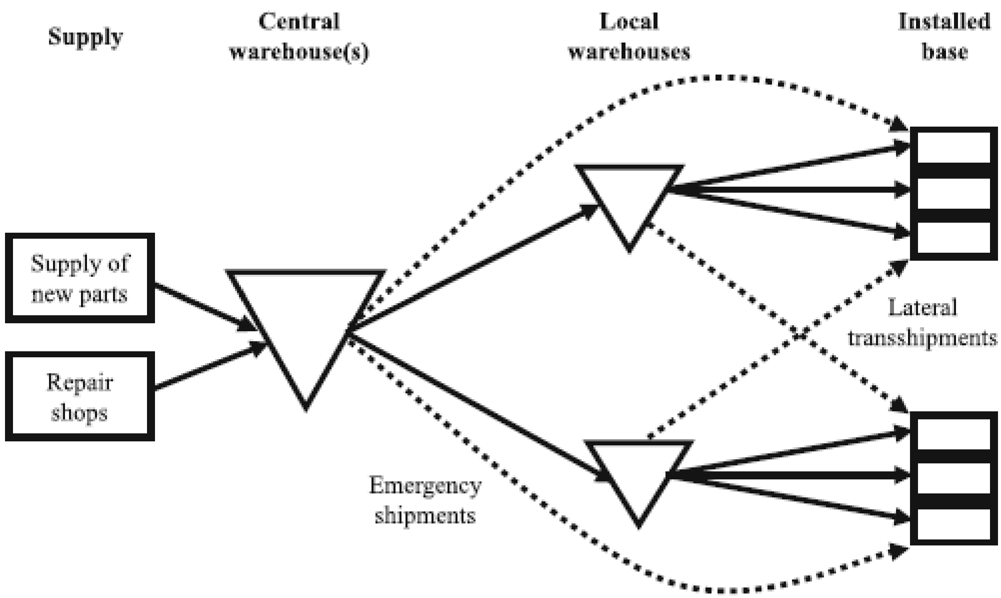

Figure 5: Van Houtum and Kranenburg's (2015) graphical representation of a common spare part network.

The emergency and lateral shipments are used when the demand cannot immediately be fulfilled at the local warehouse. If these shipments are not possible, the parts will become backordered (Van Houtum & Kranenburg, 2015). Shipments in a distribution network can be performed by different transportation modes; air, road, rail and sea transportation. Air transportation is often used for time sensitive and emergency deliveries, such as backordered spare parts, due to that this transportation mode can provide fast service over long distances. However, air transportation is the most expensive compared to the other transportation modes, which makes it more justifiable for expensive and light-weight articles (Jonsson & Mattsson, 2011; Lumsden, 2007). Additionally, of the four transportation modes, air transportation has the significantly largest emissions of CO_2 per tonne-km, which is not desirable from a sustainability perspective (McKinnon et al, 2015). Another aspect to consider with air transportation, which is the same for also rail and sea, is that it is only possible between different terminals. Here, the flexibility of road transportation has an advantage since deliveries can be transported directly from a supplier to the customer (Jonsson & Mattsson, 2011).

Spare parts inventory is connected to high costs and therefore the inventory management is of high importance. One of the reasons for the difficulties in managing spare parts inventory is the intermittent demand, which makes the forecasting process difficult to perform with accuracy (Lengu, Syntetos & Babai, 2013). Furthermore, according to Blumenfeld et al. (1999) the longer the replenishment lead time is, the higher inventory level is required in order to address the demand uncertainty. The required inventory level for retailers to avoid stock-out is therefore highly dependent on the replenishment lead time. Another important aspect to consider according to Lengu, Syntetos & Babai (2013) is the classification of spare parts. Especially when there is a large amount of spare parts, it is not beneficial to assess the parts individually. Classification aims to address which type of part should be kept in inventory and which are not.

2.3 Automotive Aftermarket

The aftermarket is the part of the products life cycle that occur after the sale, this can be regarding services or spare parts (Phelan et al, 2000; Farris et al, 2005). For Volvo, the aftermarket supply chain includes "*the activities required for ultimately securing the uptime for the products. The process starts at the supplier premises and end at the final customers*". When considering the automotive aftermarket, the availability of spare parts is of high importance (Freichel, 2010).

The aftermarket is a large part of a company's business and can stand for a big part of the revenue and contribute to business growth (Rushton, Croucher & Baker, 2014). To use the entire product life cycle can be strategically beneficial since the profit from the products can be increased. Further, the aftermarket also affects the customer experience and relationship. Providing good service can enhance the relationship with customers and result in long term relationships (Dombrowski et al, 2011).

One of the reasons for the high profit potential in the aftermarket is that the price for spare parts and after sales services is less vital for the customers. In the automotive industry one of the reasons for this is due to the importance of vehicle up-time. A vehicle off road is costly for the customer and therefore the reparation of the vehicle is of high priority (Freichel, 2010). Furthermore, the aftermarket is less sensitive to economic cycles (Dombrowski et al, 2011). This means during recessions, where the new product sales are lower, the after sales are still stable.

As previously mentioned, the aftermarket brings a lot of opportunities. However, there are also some aspects of the aftermarket and its SC that increases the complexity compared to the manufacturing SC. For example, in the automotive industry the complexity is affected by the number of different vehicles. The increasing number of vehicles types also affects the number of spare parts that need to be provided (Freichel, 2010). Additionally, the cost and time competition is constantly increasing which results in need for continuously improvement.

The complexity is further increased by that the aftermarket needs to provide products that are not only currently on the market, but also previous product that has been discontinued (Cohen, Agrawal. & Agrawal, 2006). Additionally, does the after-sales SC need to deliver more than a manufacturing SC. Cohen, Agrawal and Agrawal (2006) describes the need from the after-sales SC as higher since it needs to deliver not only raw material or finished products but also deliver parts, people and infrastructure. One fundamental difference between the SCs, described by the same authors, is that the after sales SC as opposed to the manufacturing SC cannot produce services in advance of demand. Further differences in the SCs are described in Table 1.

Table 1: Manufacturing Supply chain compared to the after-sales services supply chain adapted from Cohen, Agrawal & Agrawal (2006)

Parameter	Manufacturing Supply Chain	After-Sales Supply Chain
Nature of demand	Predictable, can be forecasted	Always unpredictable, sporadic
Required response	Standard, can be scheduled	ASAP (same day or next day)
Number of SKUs	Limited	15 to 20 times more
Product portfolio	Largely homogeneous	Always heterogeneous
Delivery network	Depends on nature of product; multiple networks necessary	Single network, capable of delivering different service products
Inventory management aim	Maximize velocity of resources	Pre-position resources
Reverse logistics	Does not handle	Handles return, repair and disposal of failed components
Performance metric	Fill rate	Product availability (uptime)
Inventory turns (The more the better)	6-50 a year	1-4 a year

2.3.1 Challenges in the Aftermarket SC

Some of the major challenges in SCs today are described in Figure 6 below. The most important factors to consider are cost reduction, customer requirements, demand variability, SC visibility and inventory management (Rushton, Croucher & Baker, 2014).

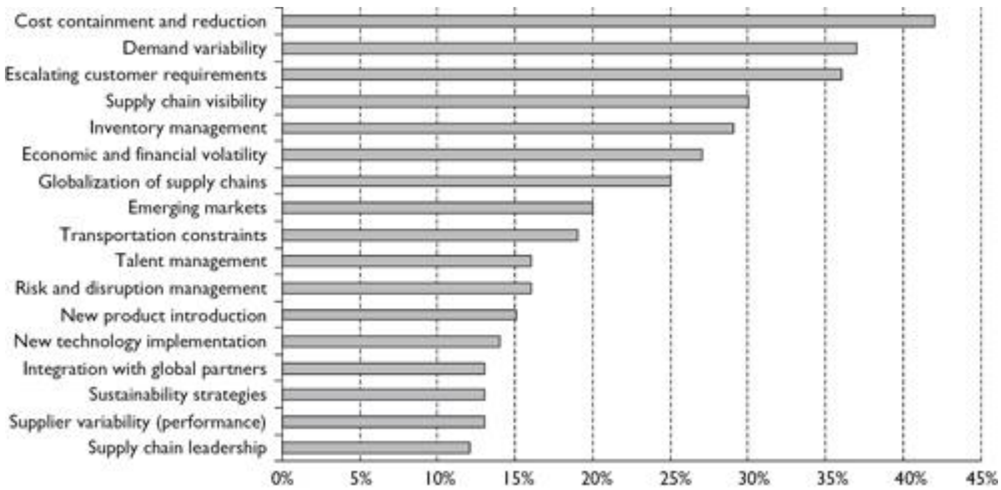

Figure 6: Main challenges driving the SC agenda (Rushton, Croucher & Baker 2014).

One factor that affects several of the above mentioned challenges is lead time. According to Chopra and Meindl (p.328, 2013), *"lead time is the gap between when an order is placed and when it is received. "In* the aftermarket this is more complex than in the manufacturing SC since the customer need can occur wherever there is a customer. In comparison to the manufacturing SC the areas of production are limited, while a spare part for end user can be needed anywhere (Cohen et al, 2006). Furthermore, the lead time required for manufacturing and delivering product is one of the main reasons why inventory is required. Usually the customer in need of a product cannot wait for the part to be produced since the need is instant (Rushton, Croucher & Baker, 2014). The lead time gap is the difference between the actual lead time for supplying the required product and the lead time that is required by the customer. The smaller difference between the lead times the smaller is the required inventory (ibid). Therefore, there is a savings potential in reducing this gap since inventory costs can be reduced. Some issues related to high inventory levels are obsolesce, cost of inventory management and tied up capital. If inventory levels can be lowered, a lot of these issues can be resolved (ibid). Furthermore, high stock levels reduce the visibility in the SC, which can hide issues (Christopher, 1998).

In order to cope with the shortened lead times and uncertainty in demand organization's needs to be flexible (Christopher, 2000). An agile SC is characterized by flexibility and high level of maneuverability (Christopher, 2000; Jonsson & Mattson, 2011). According to Constantino et. al. (p.451, 2012) "*An agile MSC may be defined as a network of different companies, possessing complementary skills and integrated with streamlined material, information and financial flow, focusing on flexibility and performance."* Where MSC stands for manufacturing supply chain. An agile SC is especially suited for environments where there is unpredictable demand and high variety in both variability and volume (Christopher, 2000).

Typical characteristics connected to an agile SC are according to Christopher (2000) that the SC is market sensitive, virtual, process integrated and network based. Market sensitivity is related to the SCs ability to adapt to changes in the market demand. This means that the SC should react to actual demand rather than forecasts. With a virtual SC Christopher (2000) means that the SC should be information based rather than inventory based. This requires information sharing and transparency that can only be achieved by process integration, which relies on collaboration between actors. Phelan et al. (2000) further supports the importance of information communication in order to create an effective aftermarket support. The network based SC is also important since actors are no longer competing individually, but the entire SCs performance is affecting the result for each actor (Christopher, 2000).

2.4 Customer service

Increased competition makes it crucial for companies to differentiate themselves in order to achieve successful business. The expectations from customers are increasing along with increasing technologies and development of products and services (Phelan et al, 2000; Ruston et al, 2014; Bergman & Klefsjö, 2010). Customers do not only choose provider for the product's perceived value but also for the quality and price of the services (Cohen & Whang, 1997). Therefore, one way to distinguish one from others is to focus on the customer, i.e.

increase customer satisfaction (Phelan et al, 2000). It is important to understand that there are different needs that customer have. Bergman and Klefsjö (2010) describe these as spoken and unspoken customer needs. Unspoken needs can be either what the customer find self-evident, or it can be needs that the customer themselves are not aware of. The spoken need is the expected need of the product or service, and is often the need that is discussed when it comes to customer need. The different needs are described in the Kano-model which identifies three needs, basic, expected and excitement needs. The customer satisfaction can be affected by all the categories. However, it is by performing well in the expected needs area or fulfilling the excitement needs that can increase customer satisfaction. By only fulfilling the basic customer need the satisfaction cannot be increased, nevertheless if these needs are not fulfilled, the customer will be dissatisfied (Bergman & Klefsjö, 2010).

One common issue with customer satisfaction or customer service levels is that companies have problem with the definition (Rushton, Croucher & Baker, 2014). That is why it is important to have a clear definition and measurement of what customer service actually is. Since customer service also differs between markets and segments this is also something that needs to be taken into account when deciding and evaluating the customer service performance (Rushton, Croucher & Baker, 2014).

One increasing demand from customers is the level of service and availability (Phelan et al, 2000), which is also linked with logistics services (Rushton, Croucher & Baker, 2014). This is not at least important in the automotive aftermarket due to the importance of vehicle up-time (Freichel, 2010). Additionally, it is important to balance the service with the demand, since otherwise the risk spending more than the customers actually demand is increased (Rushton, Croucher & Baker, 2014). The level of service that should be applied also needs to be calculated carefully. The closer to 100% availability service you get, the higher the cost (see Figure 7). What level is justifiable differs for different scenarios. Keeping a 100% service level is often not a viable option due to the costs related to this service level.

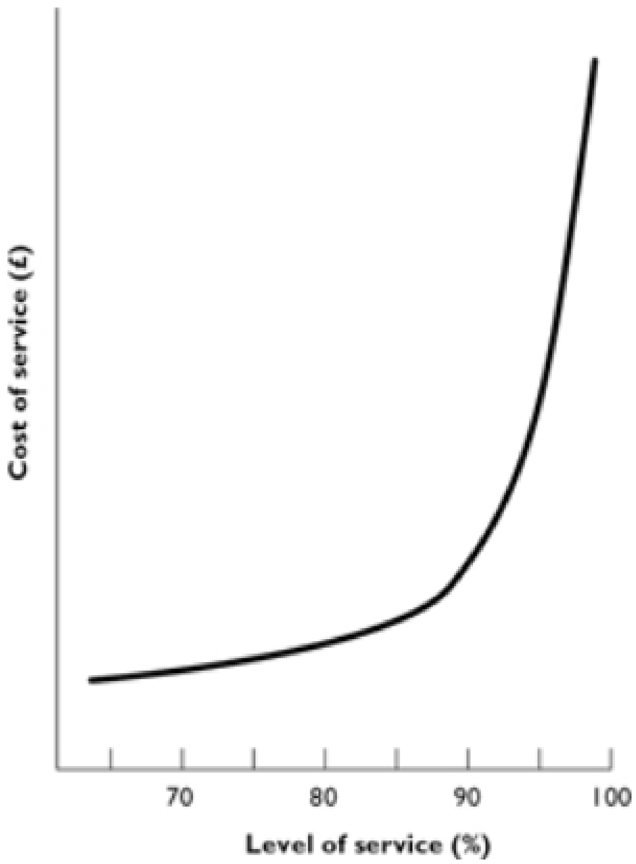

Figure 7: The relationship between the level of service and the cost of providing that service (Rushton, Croucher & Baker, 2014).

2.4.1 Backorders

"Backorder refers to the unfulfilled orders for which a customer is ready to wait for some time. Backorder of a specific company is considered an essential measure of the quality of its customer service and of the effectiveness of its inventory management system." (Deghedi and Ibrahim, p.230, 2013). This means that when a product is not available in stock, the customer order becomes a backorder. Unless the product availability is 100% BOs will occur. Stock-outs can occur due to different reasons. It can be as a result of internal issues, such as poor planning or manufacturing issues, or it can be due to external reasons such as supplier shortage or environmental circumstances. However, regardless of how refined the planning method is, when working with volatile demand the forecasting will end up wrong at some point (Christopher, 1998). When considering stock-outs the effect of this can be large, not at least in a customer service perspective but also in reduced revenue due to loss of sales (Rushton, Croucher & Baker, 2014).

When the product is not available, i.e. the inventory is empty, the BOs accumulate. The further down the SC, in the case of the automotive aftermarket this means at the dealers, the lower the BO level will be as a result of order amplification. However, the time to recover the BO will be longer, since the product needs to travel through more steps in the SC (Deghedi and Ibrahim, 2013). This increasing BO volume is highly affected by the level of information sharing, in transparency environments the effect is lower (Ibid).

3. Methodology

The thesis is of qualitative nature, where the empirical findings are compared to relevant literature in order to answer the research questions. To get reliable results both first and secondary data has been collected. The data was later on analyzed in order to provide a future recommendation for in what direction the company should go in the investigated area. How the research was performed and methodological decisions taken are described in this chapter. Finally, a validity and reliability investigation is presented.

3.1 Data Collection

The primary data consisted of interviews, study visits, a small benchmark and a case study. The interviews were performed in two different ways, face to face and through Skype. There were also two questionnaires sent out by email. Additionally, informal conversations with people at Volvo as well as observations also contributed with information which has been used in the report. The study visits were performed at Swerea and UniCarriers. The study visit at UniCarriers is also considered as a small benchmark which will be described further below. The secondary data mainly consists of internal documentation retrieved from Volvo's data base and provided by involved people.

3.1.1 Interviews

The first step in the thesis was to get an understanding of how the current situation looked like. This was done in order to see where improvements could be made and where 3DP was a possible option. To get a broad and diverse view of the situation today at Volvo, interviews were performed to get primary data. The interviewed people from Volvo were from different parts of the aftermarket logistics, purchasing, strategy and research & development. Some of the interviewees were mainly be from the operational side, while others had a managing role for the processes. Number of interviews and from which are within and outside the company is presented in Appendix I. A broad view is believed to improve the possibilities for conducting a good analysis and increase the chances of finding solutions and improvement suggestions. Another reason to interview different people was due to that the aftermarket distribution differs between different brands and market segments. These interviews are believed to add interesting data that could be used to locate issues in the current situation. Interview objects were initially decided with help from the supervisor from Volvo. Later on interview objects were provided during interviews, from people who had knowledge about the BOR and 3DP work performed within the company.

The meetings performed were face to face meetings and Skype meetings. Additionally, there was a questionnaire sent via email. For the meetings, notes were taken by both interviewers. When possible, face to face meeting were preferred since this type of interview method is suitable for investigations (Kothari, 2004). The initial interviews were performed in an unstructured way which provides a larger freedom for the interviewers and suits a descriptive study (ibid). As the project progressed the interviews became more structured since the interviewers had more information to base the questions on. This type of interview is described by Bryman & Bell (2003) as a semi-structured interview, where some questions are prepared in advance but the freedom is still maintained. When face to face meeting, due to geographical restrictions, was not possible the interviews were performed via Skype. These interviews were performed in a similar way to the face to face meetings. The duration for each interview differed between 30-60 minutes dependent on subject and knowledge by the interviewee. The third approach used was via email. This was done by a series of questions that were constructed by both the interviewers and formulated so the risk of misinterpretation was as small as possible. If data needed to be validated or additional data was needed interviewed people were contacted a second time. To add to the validity of the result, the notes taken during interviews were also reviewed several times.

3.1.2 Study Visit

Two study visits were also performed, one at UniCarriers and one at Swerea. The one at UniCarriers were mainly performed in order to get additional data regarding the BOR process and compare Volvo's process to UniCarriers' and is therefore considered as a benchmark. UniCarriers was visited since the theoretical framework on the subject was not deemed as sufficient. Due to certain restriction from Volvo's side a benchmark with a direct competitor was not possible to perform. A functional benchmark was therefore decided upon. A functional benchmark compares the company's own processes to another company's similar, but not identical processes (Patterson, Keppler & Mapson, 1995; Kozak, 2003). Kozak (2003) also describes this type of benchmark as a non-competitive one. A functional benchmark is suitable for when having a future perspective (Patterson, Keppler & Mapson, 1995). This also suited the scope of the thesis. The benchmark was conducted at the company where data was gathered through a meeting with the Director of Supply Chain Management who had prepared a presentation of the BOR process. A set of questions were prepared in advance but the main questions were added during the meeting. The data collected was recorded by notes and when concluded sent to the interviewee for validation.

There are several reason why performing a benchmark is a good idea for companies. According to Patterson, Keppler & Mapson (1995) a benchmark can be used to becoming more competitive, meet customer demand and warn in case of failure as well as promote better problem solving and provide an education and creativity boost. This is further reason why a benchmark seemed beneficial to conduct.

The study visit at Swerea was performed at the company in Mölndal. Two additional employees from Volvo were present at this visit and contributed with information and questions. The visit started with a meeting with three members from Swerea, who presented the company and 3DP as a technique. This was followed by an open discussion and questions regarding the use of 3DP in the BOR. After the meeting there was a visit to the workshop where 3D-printers and 3D-printed products were shown and described. The study visit was documented in both writing and pictures. This study visit was enabled due to previous collaboration between Volvo and Swerea and provided additional updated data regarding 3DP as a technique as well as cost, capacity and material data.

3.1.3 Case Study

Woodside (p.1, 2010) describes a case study research as "*an inquiry that focuses on describing, understanding, predicting, and/or controlling the individual*". A case study is used to provide knowledge and insight to a topic that is not quite understood or previously investigated and is a beneficial way to provide information on actual events, affected by the natural environment where the case is performed (Yin, 2014). Based on this it was deemed relevant to perform a case study in order to answer the second and third research question. The case study was performed after the current state analysis since in order to get a realistic result from the case study it is important that the researchers are familiar and understand the case environment and context (Yin, 2014).

The objective with a case study research is not to provide a general result for a wide population. The main reason is according to Campbell (1975) and Yin (1994) in Woodland's (2010) book for conducting a case study is to probe theory related to the examined situation. This is further a reason for why a case study was decided upon. The aim of the case was to be able to provide a limited proof, based on the theory and actual situation.

The case study was decided upon to provide visualization for an actual BO scenario where 3DP could be beneficial. Firstly, the area of the where the case study should be applied were decided. From this area, data was collected regarding BOs for the last 12 months. The orders were urgent and emergency since these are crucial with regards to lead time. The data were sorted due to different criteria such as origin, time to solve, order quantity, weight and standard cost. From this data, 15 articles were investigated in order to assess printability. Verification from 3DP specialist was not possible in this stage and therefore the assessment was performed by the thesis workers. One of the products was followed through the BOR process in order to make calculations. These calculations included cost, lead time and environmental impact and were made both for the actual scenario and if 3DP could have been used.

3.1.4 Literature Review

Simultaneously, alongside the current situation mapping, a literature review was performed. The literature review resulted in the theoretical framework of the thesis, which together with the empirical findings provided the base for the analysis of the current and possible future state at Volvo. The literature review contains theory regarding and related to the subjects 3DP and BOR processes. It is considered important to have a good foundation in the literature since investigating previous work is used to see to what extent the investigated issues are researched. Therefore, the risk of unnecessary rework can be diminished. The 3DP theory investigated was particularly in the area of logistics. This decision was made due to the scope of the thesis which mainly focuses on the logistic aspects. The literature study was initiated from the beginning since it was deemed important to get an early understanding of the topic that will be investigated and to be able know what empirical data to look for. The literature about 3DP contains background facts about the technique, benefits, drawbacks and applications in the automotive industry as well as trends and future prospects for the technique. The base of the theoretical framework consists of articles and books collected mainly from Chalmers library's databases. Example of search words used were among others; *3D-Printing, 3D-Printing AND trends, additive manufacturing, backorders AND cost, distribution chain AND aftermarket AND lead time, emerging technologies, automotive aftermarket AND 3D-Printing.* Additionally, were books provided by the supervisor at Volvo as well as found in previous course literature. Regarding 3DP, material such as news articles and investigation reports were also provided by internal sources.

3.1.5 Internal Documentation

Internal documentation from Volvo was reviewed as well. This data was provided by both the internal website Violin and the shared team place as well as from interviewees and contacts. The internal documents mainly provided data regarding processes at Volvo and information about the company. However, since 3DP is a hot topic at Volvo there was also previous work performed in this area that could be provided and used. Additionally, Volvo had access to research about 3DP and its development that help support the theoretical framework.

3.2 Analysis Phase

The analytical phase started with research question one. With foundation in the theoretical framework the current state at Volvo was analyzed together by both thesis workers. A brainstorming session was the initial part of the analysis. During this session, all relevant areas were brought up and discussed. The session was documented one a white board and provided a holistic view. After the brainstorming session both thesis workers finalized the analysis in the report. This was done with collaboration and continuous discussions. The analysis of research question two was mainly based on the case study and the analysis and findings from research question one and the empirical findings. The case study was used as visualization and a confirmation that the previous analysis could be considered as valid.

The third research question was analyzed based on previous knowledge and findings. The analysis was initiated by a brain storming sessions similar to the one in research question one but with a higher degree of freedom due to the need for speculations in this question.

During the thesis, progress meetings both with the supervisor at Volvo and Chalmers were held continuously to ensure that the thesis was proceeding according to the time plan and in the right direction. Updates and material were sent mainly by e-mail and the feedback was received in face to face meetings. The feedback was later revised and taken into consideration when making improvement in the thesis work and written documentation. A visualization of the thesis process can be seen in Figure 8.

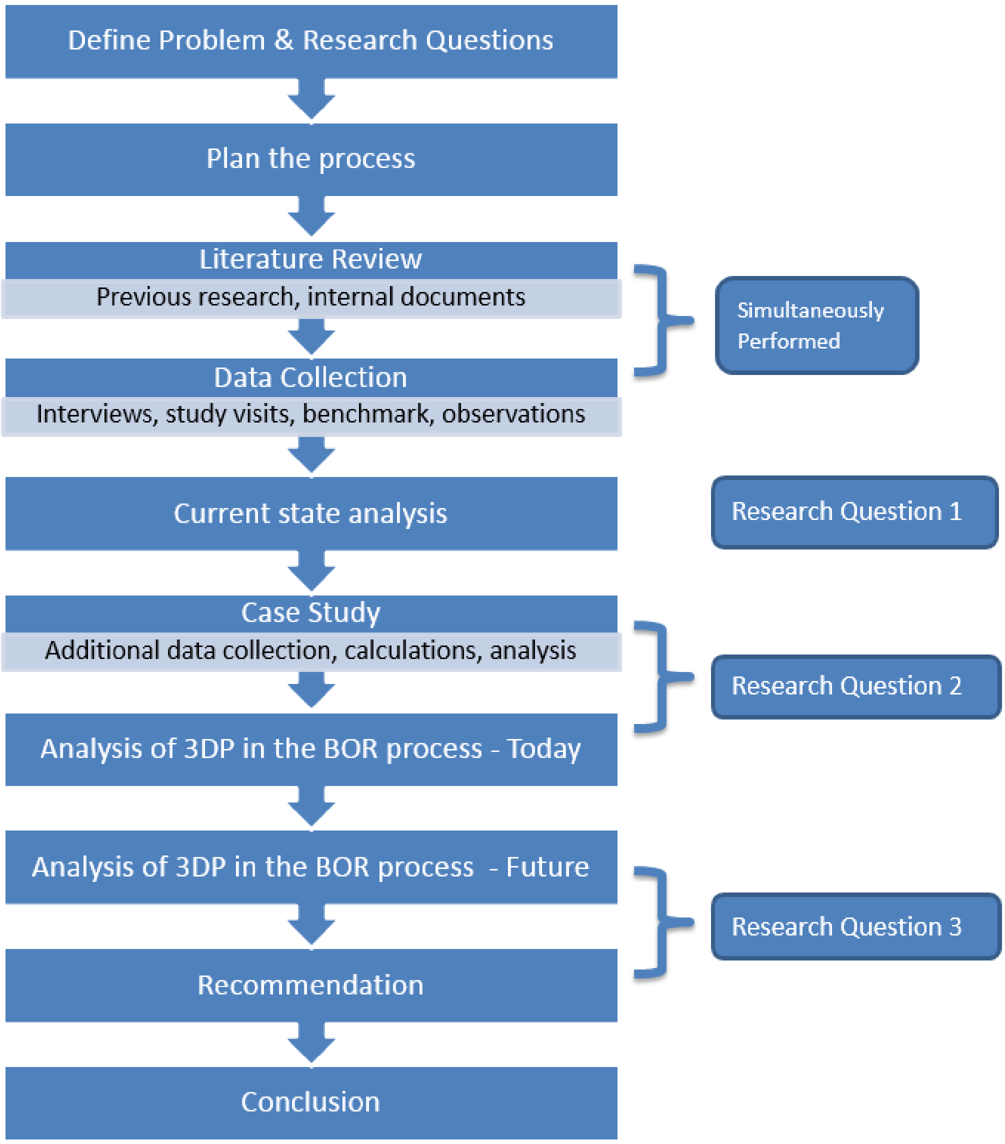

Figure 8: Illustration of thesis process

3.3 Research Design

This thesis is a qualitative study which based on the reasoning below is deemed as a suitable approach for this type of thesis. As opposed to a quantitative research approach, a qualitative approach is used to interpret how people experience different situations. According to Merriam (2014) a key component to a qualitative study is to understand situations from the participant's perspective, not the researcher's. The researcher is the person who collects and analyses data in a qualitative research, which is connected to both advantages and disadvantages. There is a risk that the researcher's own opinion and experiences affect the analysis in a biased way. This affects the result and should therefore be monitored to see how it affects the result (Merriam, 2014). In this research, there are two researchers interpreting the result, and therefore this risk is diminished since it is seen from two different perspectives. This is also supported by Merriam (2014) who states that having two or more researches investigating the same data is one way of ensuring validity and reliability which will be discussed in the Chapter 3.3.1. Additionally, the support from supervisors helped keep the perspective objective during the thesis progress.

That the researcher is the main tool in a qualitative research has its advantages. One is flexibility, meaning that data can be collected and analyzed immediately. At the same time, data can be collected both verbally and nonverbally and the responses achieved can be clarified with communication and checks with respondents. Therefore, qualitative research is perceived as an adaptive and responsive way of conducting research (Merriam, 2014). During the thesis progress confirming data with interviewees has been done in order to validate the result and increase credibility. Qualitative studies are specifically suited and applied where there is a lack of theoretical data on the subject. When this is the case, it is important to gather information and data to build hypotheses or concept rather than testing existing ones, this is called an inductive process (Merriam, 2014). This was something that could be seen in especially the BOR theory, where limited information could be found. Therefore, the benchmark was performed. There are both advantages and disadvantages with using a functional benchmark. Since the comparing company is not a direct competitor, the information sharing is likely to be higher. However, the data collected is not directly suited for the company’s processes, and from another culture and industry perhaps, which means that the information transfer can be more difficult (Patterson, Keppler & Mapson, 1995).

The final result of the thesis will be of conceptual nature and the recommendation will provide guidelines to how Volvo should proceed in this area regarding 3DP and BOR. This is further in line with Merriam’s (2014) description of the result of a qualitative research, which is often presented in a descriptive way rather than by numbers and Figures.

3.3.1 Validity and Reliability

Internal validity means how well the result found by the researches match the actual situation, i.e. that it measures what it aims to measure (Merriam, 2014; Kothari, 2004). A common method of ensuring the internal validity of the material is to use respondents’ validation. This means that the data collected by for example interviews are checked with the respondents in order to get feedback and see that the interpretation is correct (Merriam, 2014). As mentioned this has been done continuously during the thesis. External validity is related to how well the result can be applied to other situations than the one investigated. I.e. how general is the study (Merriam, 2014; Bryman & Bell, 2003). A generalization of this study can however be difficult, since the reader will only be provided with the specific case from Volvo’s environment. However, since several people were contacted, within as well as outside the company it is believed to add to the validity of the study. Further have several types of triangulation been used which is believed to increase the validity and reliability of the report. This has been done by using several methods of data collection, two investigators and from several sources. The validity is increased by that several people where asked in order to confirm information. The interviewees contacted were further mentioned several times by more than one person who leads us to believe the right people were contacted. Additionally, a meeting regarding 3DP within the Volvo Group was listened in on in the final phase of the thesis, where several of the interviewed people were present. Therefore, the right knowledge within the Volvo Group is believed to have been captured.

Reliability is to what extent the result or findings of a study can be replicated (Merriam, 2014; Kothari, 2004). This means that the result of the research would be the same if the research was performed again. Reliability can contribute to validity assuming that the method used is valid. I.e. a reliable tool does not need to be valid and in this case, it will not be useful for contributing to the research validity (Kothari, 2004). In qualitative research, this can be an issue since human behavior is not static (Merriam, 2014). This does not mean that qualitative researches are not reliable, but a more important question to answer is whether the result is coherent with the data collected (Merriam, 2014). Due to the nature of the interviews that were performed in an unstructured and semi-structured way the result can be difficult to compare and replicate. Even so, it is believed that the methods used are suitable for this type of investigation and therefore considered as increasing the reliability. When it comes to the reliability of the secondary data it is important for the researchers to investigate the data before applying it (Kothari, 2004). By careful selection, from trusted databases, and additional comparison between literatures, this is believed to further add to the reliability.

One issue with the qualitative approach is that the writer needs to convince the reader the assumptions made are trustworthy (Merriam, 2014). This is one of the reasons why the case study was performed since it can in a more quantitative way, with numbers, back up the qualitative result. A case study research can however be viewed as a qualitative research method (Yin, 2014; Woodside, 2010). Even though, it is not restricted to this, and can contain quantitative methods as well. By using several tools, the credibility of the research is enhanced (Woodside, 2010). There is no particular method regarding analysis or data collection required by the case study methodology (Yin, 2014). Therefore, the data collection has been done by both additional interviews as well as from data systems which provided more numerical data regarding products, costs etc. The data collected for the case study was received from several people and the data was additionally confirmed when it was deemed necessary. This is believed to have increased the validity of the result. One drawback is however that the product chosen was not confirmed printable by a 3DP specialist, but only assessed by the thesis workers. Additionally, the analysis of the future state should be considered as speculation based on assessments. Due to the several uncertainties regarding 3DP as a technology the aim for the future scenario analysis is to provide an indication of direction rather than exact science.

4. Empirical findings

In this chapter the empirical findings are presented. The findings are compiled from interviews, informal conversations and internal documents at Volvo as well as from Volvo Group's homepage. The chapter aims to provide a background to the studied area. The chapter contains information regarding Volvo Group, the current BOR process, spare part life cycle and 3DP at Volvo. Due to the scope of the case study performed in research question two, Volvo construction equipment is also introduced more thoroughly in this chapter. Additionally, empirical findings from outside the company are presented. This is provided from study visits and interviews with suppliers, Swerea and Unicarriers.

4.1 Volvo Group

Volvo Group is "one of the world's leading manufacturers of trucks, buses, construction equipment, drive systems for marine and industrial applications" (AB Volvo, 2015). Volvo Group consists of several brands and joint ventures acting on different markets around the world. The brand portfolio is presented in Figure 9. The brand portfolio consists of Volvo, Volvo Penta, UD, Terex Trucks, Renault Trucks, Prevost, Nova bus and Mack. The joint ventures are with the Sunwin, SDLG, Eicher and Dongfeng brands.

Figure 9: The Volvo Group brand portfolio (AB Volvo, 2015)

Even though the brands are all represented under the Volvo Group name they target different customer and market segments. The business areas and share of net sales are illustrated in Figure 10.

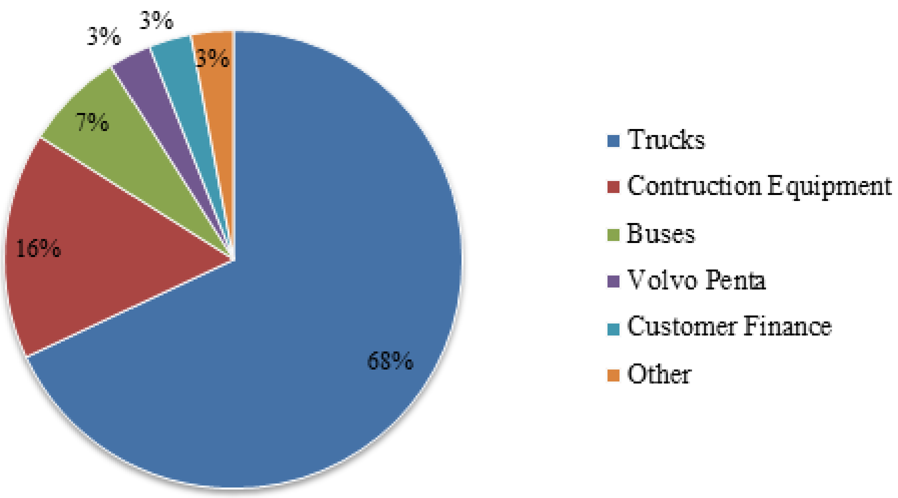

Figure 10: Net sales for the Volvo Group in 2015

The Volvo Group is present worldwide. The largest markets are Europe and North America. However, by acquisitions of companies on the Asian market this share is increasing and growing stronger. In Figure 11 the sales by market is illustrated.

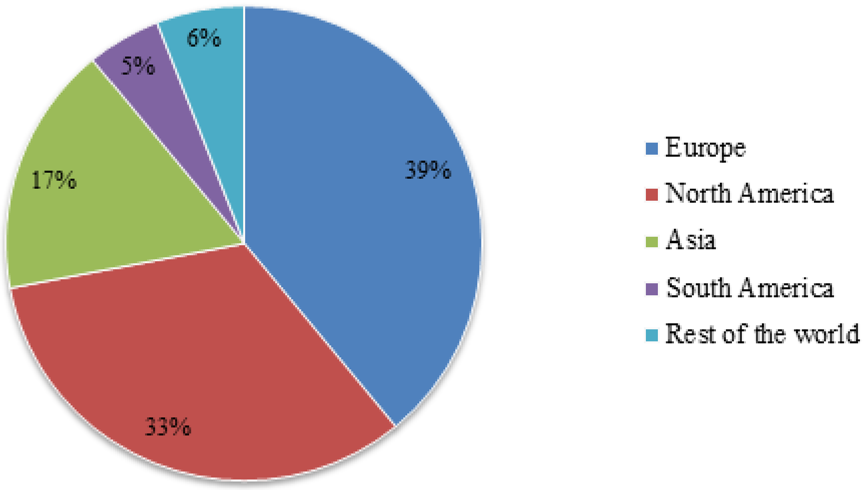

Figure 11: Sales by market 2015

The Volvo Group's vision is to *"The Volvo Group's vision is to be the most desired and successful transport solution provider in the world"* (Volvo, 2016). They have also taken on the WWF's challenge to decrease the carbon dioxide emissions per produced unit from the Volvo Group freight transport with 20% until year 2020 (WWF, 2014). Additionally, the company is in a restructuring phase, where different functions are reorganized. A main reason for this is to increase customer service and satisfaction which Volvo is focusing on to a large extent. Two main improvement areas that are of high importance for Volvo now and in the future are environmental impact and customer service. Therefore, there has been effort put into improving these areas. One area that can affect both customer satisfaction as well as the environmental impact is the aftermarket and the BOR process. The BOR process in particular impacts the customer satisfaction due to the lack of availability that the BO results from. In cases where the BO regards a critical product for the vehicle it is especially important to deliver the product as fast as possible. Otherwise the customer will lose valuable up-time for the vehicle and faith in Volvo as a service provider. When it comes to the environmental aspect the BOR process has potential to decrease the environmental imprint if lead time can be shortened. One of the reasons is that BOs are often in need of rush transportation which are more environmentally damaging than when product can be delivered within a longer time frame.

4.1.1 Volvo Construction Equipment

Volvo Construction Equipment (VCE) is among the world's leading manufacturers of haulers and wheel loaders. VCE also manufactures excavation equipment, road development machines and compact construction equipment. VCE is present worldwide and the spare parts and services are offered on 150 markets.

The purchasing organization for the VCE manages over one million active parts in total and the parts are sourced from 1900 suppliers in 37 different countries. As can be seen in Figure 12 and 13 the inventory for VCE consist of a large part, especially when considering the sales Figure presented in Figure 10 in Chapter 4.1.

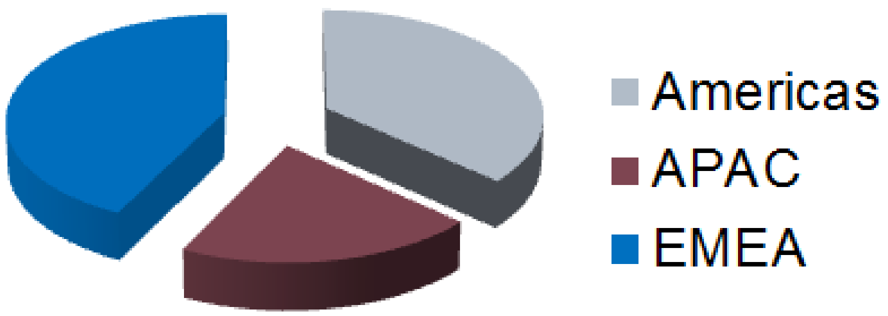

Figure 12: Inventory per region

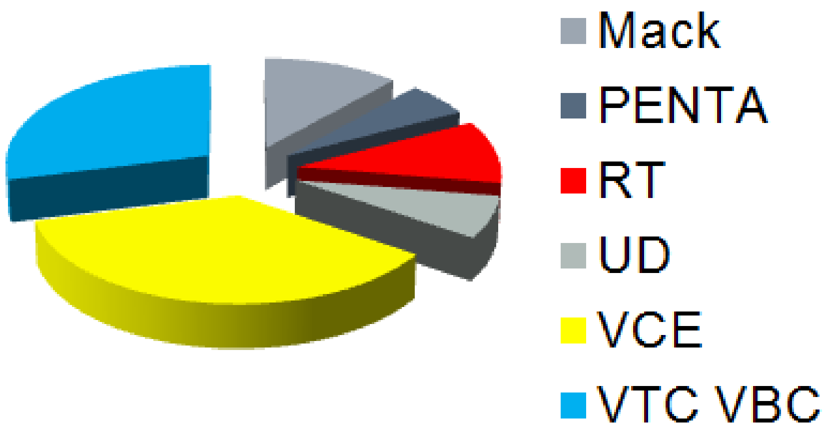

Figure 13: Inventory per brand

The reasons behind the high inventory levels, mentioned by a theoretical optimization specialist working with VCE, are among others that VCE has a higher number of spare parts. Additionally, are there many slow moving parts in this business area as well as that the VCE's vehicles have a long life cycle, which means that the spare parts need to be provided for a long time.

4.2 Current backorder recovery process

Volvo defines a BO as an order for a part that cannot be filled at the current time due to a lack of available supply. BO is a status of an order and is defined by no instant availability in the storage shelves locations (i.e. no stock of the right part number, right brand, right packaging). BOs can be initiated in different parts of the distribution chain. When the BO is initiated from the regional distribution centers (RDCs), i.e. the article is below order point, the BO is not considered being as critical as the BOs that are initiated from dealers that are a direct result of a customer need.

Volvo has a 94% service level for delivering spare parts instant from stock to their customers, which means that Volvo plans for ~6% unavailability that results in either day orders or BOs. The availability of 94% is measured at the dealers, i.e. the dealers' possibility to deliver directly to the customer when the need for a product occurs. A day order is an order which is not instantly available but can be delivered the same day, these orders are not considered as BOs even if they are registered as such by the system. Approximately 1% of the orders become BOs, which are the orders investigated in this thesis. However, this measurement has some drawbacks since it does not include customers that leave the dealer without making an order when the spare part is not available directly, i.e. they do not want to wait for the product. The part build up availability is illustrated in Figure 14.

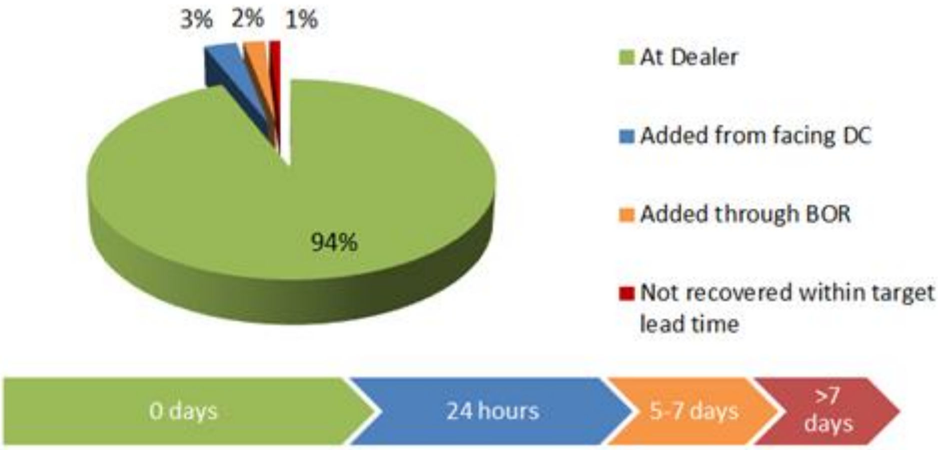

Figure 14: Parts availability and lead time

The BOR process initiates at the dealers, some independent and some owned by Volvo. Dealers provide customers with Volvo spare parts. The main responsibilities for dealers are to repair vehicles and provide service as well as sell over the counter products and new vehicles. A dealer can therefore be a reseller or repair shop etc. In total there are over 3000 dealers. In the distribution chain for the aftermarket there are different distribution centers (DC); there are approximately 6 central distribution centers (CDCs), 30 RDCs and 10 support distribution centers (SDCs) (see Figure 15).

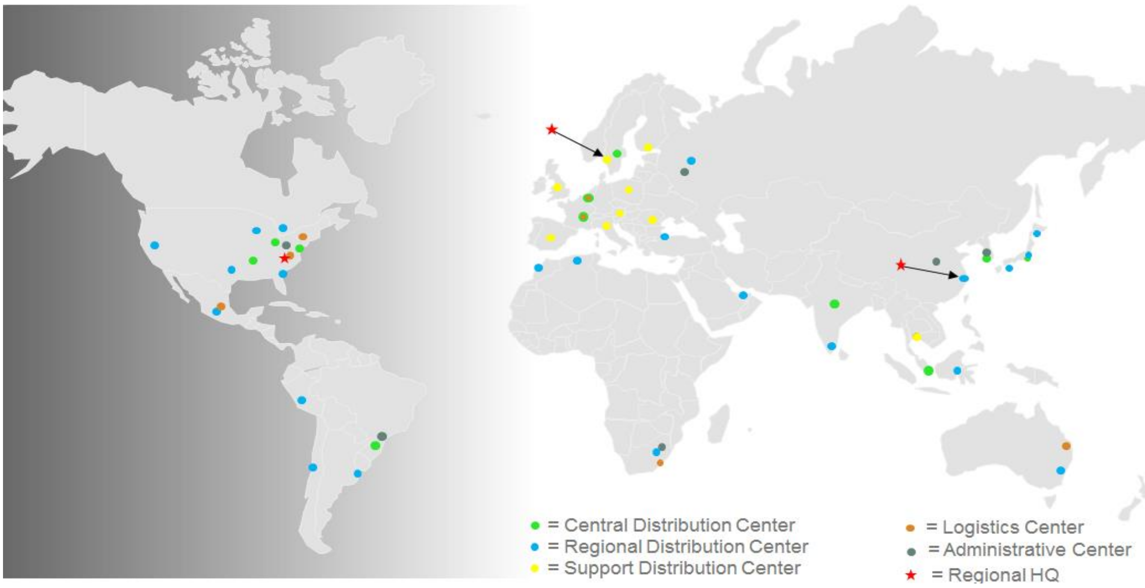

Figure 15: Illustration of Volvo's DCs worldwide

At the CDCs material from suppliers is procured and either stored or delivered to SDCs, RDCs or dealers. The RDCs get material from the CDCs and the RDC works as a CDC in regions where there is a need of having a DC closer to the customer. The CDCs are usually bigger than the RDCs and additional activities are performed at the CDCs, such as repacking and quality checks. The reason for having SDCs is foremost to be able to deliver parts faster to the customer but also to avoid critical shortages and expensive transportation costs. The

SDCs only provide the dealers with urgent orders. Typical articles put in the SDCs are medium - low frequency and heavy articles. This means articles that have too low frequency for the dealer to have in inventory, but are too frequent to be stored far away from the customers. Heavy articles are expensive to store at the dealers and rush transportation is expensive for these articles. Therefore, these articles are suitable to store in SDCs. An overview of Volvo’s supply chain structure for the aftermarket is presented in Figure 16.

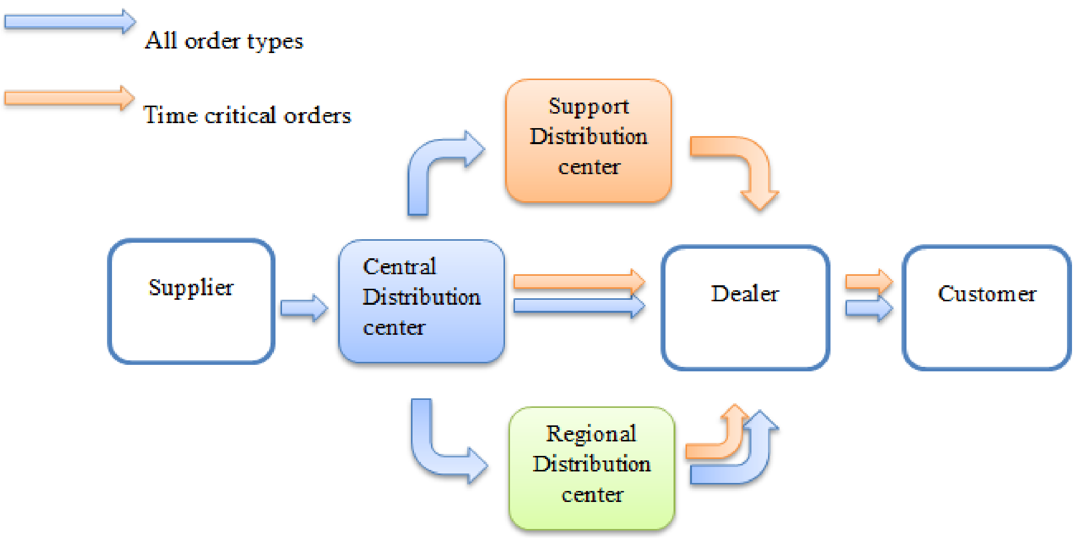

Figure 16: Illustration of Volvo’s aftermarket supply chain structure

When a spare part is not available the dealer orders the part in an IT-system that is connected to the DCs. The order is transferred automatically by the IT-system as a BO towards the closest DC depending on the distribution set-up. At the SDCs parts are never registered as BOs, since this DC only provides the dealers with day orders and if these cannot be fulfilled the order will be transferred to the closest RDC or CDC where the BO will occur. Depending on the order class requested by the dealer, the urgency of the BO will be handled accordingly. The search for the part starts regionally, if it is not available in the regional area, the search continuous on a central level.

When a BO is initiated it is categorized on a three step scale; emergency, urgent or regular backorder. A BO is categorized as an emergency BO when the part is critical for the function of the vehicle. This is also known as a VOR (vehicle off road) and is by Volvo defined as “a situation where the vehicle or engine cannot fulfill the transport assignment or purpose due to loss of functionality or without violating legislation or safety”. The emergency BOs are most critical from an uptime perspective. The urgent BOs accounts for problems associated with function reductions of the vehicle and could for instance be a motor overheating. These BOs are also known as day BOs. Regular BOs, or stock orders, concern refill order or regular dealer order and accounts for minor failures with no function reduction of the vehicle.

When a BO is registered, depending on the categorization the BO is handled by different teams. The emergency BOs are handled by the BOR-team located in Gent, Lyon and Eskilstuna. The urgent and regular BOs are handled by the continental material planners (CMPs). Today the CMP-teams are working reactively rather than proactively. This means that the work concerns solving BOs that have already occurred rather than trying to avoid future BOs. There is some communication between the BOR-team and the CMP-team in order to solve specific cases. The collaboration is mainly initiated by the BOR-team since the CMPs usually tries to avoid rush transportation that are connected to the emergency BOs. Furthermore, there are order help-desks located at RDCs in the same time zone as the customers. The dealers turn to these with questions regarding their orders.

If the BO is not recovered it needs to be escalated in order to get higher priority. For a regular BO that is not recovered the escalation is made to an urgent BO. The same principle goes for an urgent to an emergency BO. When a BO is escalated the responsibility for handling the BO can be transferred. This happens when an urgent BO is escalated to an emergency BO. In Figure 17 the escalation and handling of different BOs is illustrated.

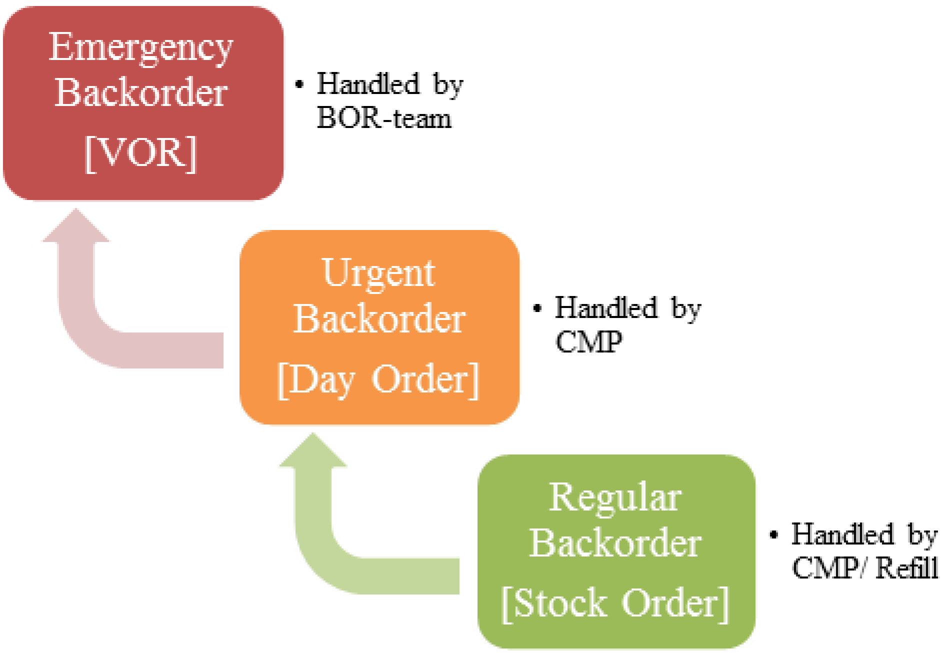

Figure 17: Backorders escalation and handling

The further away from the customer the part is available, the longer time it takes for the BOR. For an emergency order the product will be shipped from where it can be located, which means the transportation distances and lead time can be very long. This result in a lot of expensive rush transportation with modes such as air transportation, which is also, is connected to high CO_2 emissions. Even though the transportation cost is higher this cost will usually be lower than the cost for prolonging the BO. The cost is connected to several factors, such as loss of sales and bad will for the company. Additionally, each emergency BO result by Volvo estimated loss each day for the customer, independent on part. The lead time is defined by Volvo as the amount of time that elapses from a process start to end.

There are different reasons why the part cannot be delivered. The most common reason for BOs is unpredicted sales. This is followed by supplier delivery problems and supplier capability issues. Issues at the suppliers can be due to quality issues or problems to cope with the current demand and prioritization of orders. Another reason could be that the supplier might have tooling issues or that there are delays from sub-suppliers. Also, if there is not a purchasing contract in place, ongoing discussions regarding for instance price or invoices with the supplier might delay the process. It might even be that the production of the spare part has stopped. Furthermore, when a spare part is ordered by a customer for the first time it usually becomes a BO. This since articles that never been ordered before are not kept in stock. Delays can also occur due to transportation arrangement issues.

When a BO has occurred, there are different steps in order to find the part. The BOR wheel lists the possible steps of recovery for an unavailable part. Dependent on situation (part, location, business area) some or all steps need to be used. The steps are described thoroughly in a checklist. The BOR wheel is presented in Figure 18.

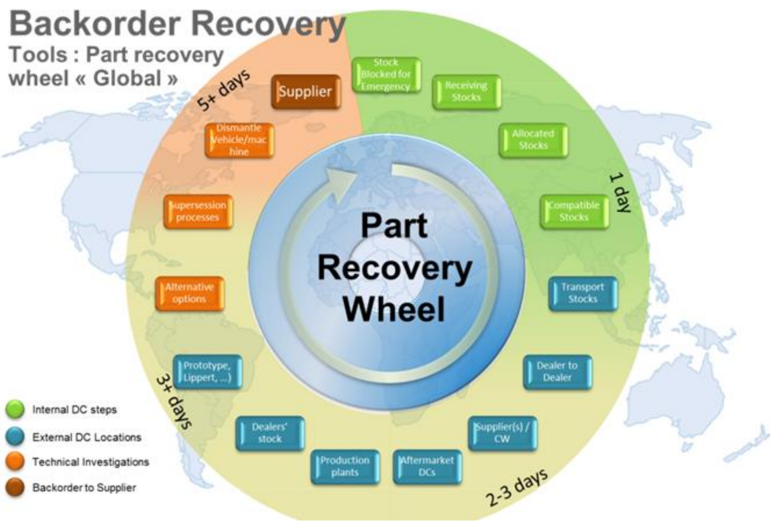

Figure 18: Backorder recovery wheel

The first step is to search for the part in the dealer facing warehouse, i.e. the internal DC steps. These steps include; search for part in stock blocked for emergency, search for part in receiving stocks, search for part in allocated stocks and search for part in compatible stocks. The search is performed in different systems dependent on in which step the recovery is performed. In what system to look and who to contact can be found in the checklist. If the part is found, it is distributed to the customer and the BOR is fulfilled.

If the part is not found in the dealer facing warehouse, the second step is to look outside the warehouse. This means initially to search for the part in transportation stock. The parts in the transportation stock can for example be; dealer returns (e.g. buy back or quantity crepancy, warehouse returns from a SDC or RDC etc.). If the part is still not found a search at other local dealers is performed. The search can be for either the brand or a compatible part from another dealer's stock.

Search for the part within the Volvo Group is the next step. This includes searching within; central or local supplier(s), CDC if the BO is handled from a RDC, other aftermarket DCs or production plants. Which solution to choose is dependent on the lead times and local situation. Further steps are to search for part in global dealer's stocks and to search for part in technical solution. Technical solutions can for example be dismantling an existing vehicle.

When the part is located the following steps are performed;

- Request part transportation
- Follow up part delivery

The follow up is done by measuring KPIs and PIs and comparing them to set target levels. The BO KPI is measured in the same way as the availability with an additional time frame aspect. This KPI is described more thoroughly in Chapter 4.2.1. The follow up is performed every week and updated into a data system that is monitored by the management.

- Update estimated time of arrival (ETA) or guideline
- Handle BO cause
- If the part is not located, aging BOs need to be escalated as previously described.

Every step in the BO wheel is not always performed. The BO wheel serves more like an illustration of possible actions to take. Furthermore, different illustrations have been encountered at Volvo, which results in that everyone do not work according to the same version of the BO wheel. There is an ongoing change initiative to improve the current BOR process to deal with issues with processes as well as increase the trust for the BOR. This BO project includes improvement areas regarding the policy of defining emergency BOs, communication and the internal operation at materials management.

One issue today that is affecting the BOR-process is regarding the BO classification from the dealers. Due to the previous performance of the delivery, the trust regarding urgent orders is quite low. This result in dealers placing emergency orders even if the order should be classified as urgent orders. The reason behind this is that the dealer wants to make sure that the product arrives on time. However, by doing this the urgent orders are prioritized according to an emergency order which impacts the other orders negatively. A new emergency BO policy is therefore being developed.

To further increase trust in the BOR-process Volvo focuses on improving the handling of BOs. One action was the development of a checklist in order to create a standardized way of working with BOR. The checklist is based on the steps in the BO wheel, but explains the work procedure in detail. For every recovery step there are work instructions for the different brands. Furthermore, possible improvements are identified in the checklist. The checklist aims to create a standardized way of working as far as it is possible within the global context. For the different regions some steps in the checklist might differ. This is mainly because of the several different IT-systems and differences in distribution system that are used within the

Volvo Group. It is up to the line managers to ensure that the steps in the checklist are followed. However, reluctance to the checklist has been noticed among the CMPs. The reasons behind this are that the checklist is found too cluttered together with that the structured way of working is not appreciated by everyone.

Another improvement action in the handling of BOR is to standardize a way to enter root causes of the BOs in the IT-system in order to be able to identify common causes. With a clearer presentation of data, it would go faster to identify root causes. These actions result in a more proactive BOR-process which can result in a decreased number of BOs.

4.2.1 Backorder recovery KPI

The purpose of the BOR KPI is to measure how fast the Volvo Parts organization can handle and mitigate warehouse shortages. To measure the performance of the BOR Volvo uses a specific BO KPI. The KPI is measured in percentage of recovered BOs in a certain timeframe and can be described as a service level measured in time.

Aftermarket Backorder Recovery in % = number of order lines available within;

D+X days / total number of order lines.

D=order entry day.

The BO KPI is therefore an availability measurement. 94% is supposed to have instant availability, the rest of the orders are added to the service measurements each day when they are fulfilled. For VCE in AMERICAS the BO KPI level is set to 98,5% according to the logistic developer manager, with a D + 5 days, which means that in order to fulfill the measurement the availability needs to be 98,5% within 5 days' time.

The measurement for BOR is performed at the facing DC (RDC/SDC/CDC) towards dealer. BOR is measured from the day it is available at the facing DC. This can from the system perspective also be on a night batch. What should be noted is that the BOR KPI does not measure when the order arrives at the dealer, but when it is available at the DC.

All BOs at any place in the aftermarket are included in the measurement, this include all the DCs and all orders and order types. The set target level for the KPI differs between area, segment and brand and these levels are measured individually. However, there is also a joint target level for the entire Volvo Group which is also measured and evaluated. The parts, which are recovered within the X+days, reach the set target.

Since the regions and brands are handled differently the KPI is measured for different regions and brands. The reason for the differences in the measurement is related to several factors. For example, number of spare parts, expected level of service and brand priority in different parts of the world. The target level is also set based on a dialogue with the customers and different departments such as sales. Further, an estimation of the cost to achieve the set target is included. The availability is set towards the business area, and not the individual customers. I.e. Volvo ensures this availability to the dealers.

The two biggest markets EMEA and AMERICAS are the markets that have the most stable measurements. EMEA reaches the target most months while AMERICAS is on a slightly lower level. This is even if the EMEA target is set higher than AMERICAS. The level of BOs recovered can differ over time. There are different reasons for this, one example is quality campaigns. Further does the holiday season affect the levels; this is especially true for the APAC region. For this region however, the set target level has never been met, and therefore this is also something that is looked into to see what a realistic target for this market region is. Another reason for some of the fluctuation is the number of order lines for each segment. For areas where few lines the variation for an unfulfilled order is affecting the measurement to a larger extent.

4.3 Spare part life cycle

One important aspect to consider when designing the aftermarket spare part distribution is the life cycle of the spare parts. This since the demand on spare parts is dependent on which phase the part is. There are four phases, the initial, prime, decline and phase out phase. The initial phase means when a new product, (e.g. a hauler) is introduced on the market. In this phase the spare part demand is quite low, therefore the required volume is not as high as for example in the prime phase, where the products start to need maintenance and change parts. In this phase, the required volume of parts is higher. After the production ends the volume of spare parts gradually starts to decline. Until the year that Volvo is responsible to provide the customer with spare parts the service level is quite high, especially for the fast moving parts. However, after this year, which is usually 15 years after the purchase, according to the theoretical optimization specialist, the availability of spare parts for that product is lowered and entering the phase out period. It is in this phase where most BO with no solution occurs. For these orders the customers' perceived service is highly affected.

Another interesting aspect to the life cycle curve is how the market share of spare parts sales is changing during time. The market share is dependent on what type of spare part, age and specific product type and is therefore difficult to estimate. However, the approximated potential for genuine Volvo parts in relation to age is described in Figure 19 and can be said to somewhat follow the market trends from a life cycle perspective.

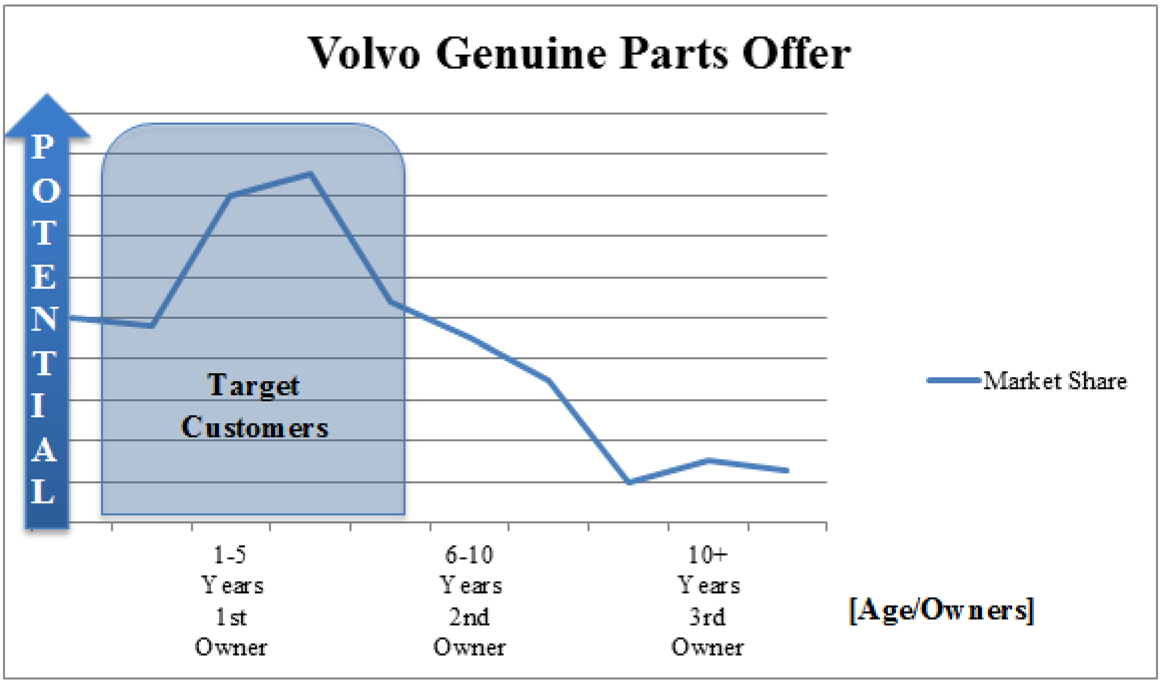

Figure 19: Aftermarket potential over a vehicles life cycle

4.3.1 Segmentation

The aftermarket is divided into different segments, Europe - Middle East - Africa (EMEA), Asia Pacific (APAC) and Americas which are all handled a bit different regarding BOs. Some differences are regarding the distribution set up and some are regarding service levels. Due to these differences, also the BOR process looks a bit different from region to region.

The parts are also divided into different segments dependent on different factors such as, cost, frequency, customer criticality and life cycle. The life cycle perspective was recently added to the segmentation and resulted in a positive outcome in form of higher availability to a lower cost. This was mentioned by both a theoretical optimization specialist as well as a project manager previously working with BOR. The reason for using segmentation is to increase the efficiency in stock keeping, control the availability and create a balance between cost and availability. The segmentation means that the spare parts are divided into groups dependent on how critical they are for the customer. The most critical parts are so called “up time critical” and are prioritized when it comes to the availability. The segmentation is on group level but sometime also on individual article, since different perspectives that are taken into account differs from different products. For example, for a slow moving part in the phase out period the availability will be lower than for a fast moving part in the prime phase, even if they are included in the same criticality segmentation. Segmentation is also used to target the right investments.

4.4 Backorder recovery at UniCarriers

Knowledge of how other companies work with BOs can give valuable insights and help Volvo develop its BOR. A company that was considered interesting to learn from was UniCarriers since the company, like Volvo, also provide transportation solutions but with a different product assortment. UniCarriers Sweden is a part of the global UniCarriers Corp and is providing forklifts of different kind on the Swedish market. Additionally, UniCarriers is providing services to all brands and education in forklift driving as well as safety and work environment. UniCarriers was founded in 2011 as a merger between Nissan Forklift, TMC and Atlet. The headquarters for the European market is located in Mölnlycke (UniCarriers, 2016). Except for providing customers with new forklifts, UniCarriers also supply spare parts and service during the forklift's life time. The aftermarket demand is, as in Volvo's case, highly fluctuating and difficult to predict. Another similarity between the two companies is that vehicle uptime is critical for the customer and therefore lead time is crucial when it comes to providing spare parts. Additionally, UniCarriers exists on different markets characterized with different requirements and aims to provide spare parts during the forklift's life cycle, which is approximately 10-15 years. The benchmark was performed at UniCarriers in Mölnlycke with the Director of Supply Chain Management. The data was collected through a presentation and an interview performed with the above mentioned person. The focus of the benchmark was on the European market.

In order to provide the customer with spare parts UniCarriers uses the following distribution setup in Europe. There are two warehouses, one located in Sweden and one in The Netherlands. Additionally, the company has contract with different transportation suppliers that should be able to provide fast delivery to customers. UniCarriers also uses service vehicles that constantly are out on the road, providing service fast where it is needed. In these vehicles there is a small amount of spare parts stored that might be needed for service of forklifts. The service vehicles are supposed to be able to deliver overnight, i.e. if a customer orders a spare part before 17:00 the part will be available before 07:00 the next day.

UniCarriers provides end customers and service technicians with spare parts when needed. The spare parts are ordered either through the service technicians or a web shop where end customers can order articles. UniCarriers has nine subsidiaries that are in contact with the customers. The placed order can be categorized in three different ways; standard order, emergency order or as a VOR. It is the customer or service technicians who categorize the orders, dependent on how fast the order is needed. When the ordered part is not available, the order becomes a BO. For UniCarriers, when solving the BOs, a standard BO has low priority. These are considered non critical and are shipped to the customer when available in stock. The emergency BOs, on the other hand, are prioritized higher and UniCarriers do what they can in order to locate the part. In case of a VOR, which is the most urgent type of BO, both UniCarriers and the subsidiaries are involved in trying to solve the BO. There are no criteria that need to be fulfilled in order to classify an order as e.g. a VOR. However, the customer pays according to what order is placed. For a standard order, the customer pays for the part, while for an emergency an extra cost is added due to rush transportation. For a VOR the customer pays more, since more resources are required from UniCarriers in order to solve this type of order.

To solve a BO there are several possible actions to take. One is to check if the part is available at another warehouse. If the part is not found, the material planner can try to force suppliers in order to get the part(s). Possible examples of forcing suppliers that could be applied are part delivery of the spare parts or to ask for an earlier delivery date. Another option is to buy spare parts from the internal production. Furthermore, there is also a possibility to take spare parts from the service vehicles. However, today the inventory in these vehicles is not visible at a central level. This complicates the search and is identified as an improvement area. The aforementioned steps are only considered in BOs concerning emergency order or VORs. There is no standardized way of working and no procedure that should be followed when solving the BOs and new employees handling BOs are trained by more experienced ones.

UniCarriers aims for a 94% service level. This means that 94% or the spare parts needed should be available for the customer when the need occurs. The availability for different spare parts are decided through segmentation based on cost and pick frequency. This is done in a system which automatically shows which products should be shelved. However, if a product is inconvenient to store or of high criticality to the customer this can be altered manually.

The main work regarding BOs is done proactively, i.e. trying to avoid BOs. A big part of this is the IT-system that has features that both plan inventory levels as well as warn if there is risk of run out. The system bases its prognoses on historical data. The system aims to create a transparent as possible environment and provide information of where parts are located. The system enables transparency from anywhere in the world which improves the possibilities to plan. With the IT-system there is less need of communication between different departments to find products. From the customer side, the amount of questions can also be reduced if they have the information right away regarding their products.

Even though the work of preventing BOs is in main focus, BOs do occur and are measured and followed up. The company also applies BO KPIs that measure the value of the current BOs, the number of order lines, as well as the overall time (in days) the BO exists. The BO KPIs are evaluated once a week or once a month depending on which KPI it is and these are occasionally presented to the management team in order to follow up the progress. In addition to these overall KPIs the material planners are individually monitored regarding the BOs they are responsible for. This is done in order to ensure a positive trend for each individual.

UniCarriers has worked actively with development of the BOR handling. Main focus has been to create transparency in the BOR process and to train humans. The transparency has been improved by a new IT-system and employees have been educated to realize the importance of having a sense of urgency when it comes to BOs.

4.5 Main findings

Volvo defines a BO as an order for a part that cannot be filled at the current time due to a lack of available supply. Customer satisfaction is prioritized at Volvo and BOs are connected to rush transportation which results in high transportation costs and increased environmental impact. Volvo has a clear distribution structure, consisting of CDCs, RDCs and SCDs, to support these urgent deliveries of BOs. Furthermore, the company has a three step categorization of BOs, which they are working on to make even clearer. Low trust in the BOR process has been experienced by dealers which have resulted in wrongly categorized orders.

Volvo has clear roles of who handles which order. They have dedicated teams that work with solving BOs. There are routines established in order to create a standardized way of working. However, the routines are not followed by all employees. The handling of BOs is different dependent on brand which increases the complexity. The many IT-systems used within the Volvo Group are experienced by employees as disturbing. Today's work is mainly reactive, but the company strives for working more proactively as well. Recently, Volvo has started to standardize how root causes are entered in the IT-system. With the better knowledge of what is causing BOs Volvo can take a more proactive approach.

The KPI for BOR is measured in percentage of recovered BOs in a certain timeframe and can be described as a service level measured in time and there is a weekly follow up of the KPI. The measurement fluctuates due to different reasons and differs from brand and region.

UniCarriers use a similar categorization of BOs as Volvo. The search pattern in order to locate a spare part at UniCarriers is also similar to the one at Volvo. However, at UniCarriers there is no standardized way of handling BOs like at Volvo. This indicates that Volvo has gotten further in the BOR handling. Furthermore, the IT-system used plays a big role for creating transparency. Volvo could especially learn from the customer visible ETA. Additionally, UniCarriers, like Volvo, follow up BOR on a regular basis and uses similar KPIs.

4.6 3D-Printing Findings at Volvo

Today Volvo is in possession of several 3D-printers. Most of the machines are used for prototypes. However, there are also machines that are used in production and for manufacturing customized tools. According to Stratasys Ltd. (2015) by using 3D-printers for manufacturing tools, the cost for tool production can be reduced by 90%, and the lead time significantly reduced. This has also been seen at Volvo, where in-house printing of tools has been produced with a 90% reduction of lead time and also to a lower cost. This information was provided by the emerging technology program manager. Additionally, Volvo has successfully tested to use 3DP to solve BOs. Both tools and actual spare parts have been printed. Within the Volvo Group there are several ongoing initiatives regarding 3DP. Today there are not much coordination activities between the different initiatives. However, this is noticed by the company and they have started mapping all 3D-activities within the Volvo Group. Even so, the exact knowledge and expertise that the company contains in still not completely mapped.

3DP is as mentioned before an interesting topic with a lot of potential which has also been prioritized at Volvo in order to grasp the opportunities it might bring. There has for example been thesis works performed, both regarding printable products as well as possible suppliers. Additionally, there have been trials where 3D printed products have been used in order to solve an urgent delivery from customers. Based on information received regarding previously performed work at Volvo the opportunities are several and in different parts of the organization. As it is today, the implementation has been mainly in production and tooling, however, the high potential for the aftermarket has been seen in several of the material received as well as during interviews.

The future potential for 3DP is also considered high according to Volvo's research. The prediction is that the speed will increase as well as the dimensions of products and difference in material. Further will the cost be reduced and the process stability will be better. Especially in the aftermarket the potential is seen to be highest in the slow moving segment, small series and where the lead time to customer is crucial.

Since 3DP is an area within which Volvo want to increase knowledge, collaboration with several 3DP suppliers has been initiated and ongoing for some time. Volvo has explored the possibilities of printing both plastic and metal parts and the product properties have shown to be sufficient for some products. However, of the 3DP suppliers which Volvo has been in contact with, only one have quality assured production and this only for the production of plastic parts. During 2016, the supplier plans to have quality assured metal printing as well. Volvo has been investigating the possibility of 3DP suppliers producing functional parts on-demand. For a 3DP supplier to produce a spare part, a CAD-file of the part needs to be sent from Volvo to the 3DP supplier. One drawback in the current situation is that the CAD-file almost always needs to be adjusted before printing, which increases the lead time for producing spare parts significantly. Furthermore, the finish/surface of the product is different when using 3DP compared to traditional manufacturing. This means that the product will be either different from the traditional products or needs rework before it can be used properly. According to a business consultant this has impact on different customers. For example, in the military segment the surface of the product is less vital than for example a truck owner, as long as the part has the correct properties. If rework is necessary, this will prolong the lead time. Additionally, today the 3DP suppliers' capacity is heavily booked, which further extends the lead time. The current lead time is estimated to be two to three weeks.

According to the innovation framework program coordination and project leader for emerging technologies, collaboration with 3DP suppliers has shown that in general the quality is too low and the price is too high to use 3DP as a production technique in the high volume spare part manufacturing. However, when it comes to VORs or BOs with high urgency the business case is different. Due to the low volumes and criticality of BOs, using 3DP is a good way of reducing the lead times, cost and the overall process time for solving BOs.

There are some main obstacles identified which Volvo has to overcome in order to implement 3DP in the organization's aftermarket. The first one is believed to be the lack of competence internally at Volvo. If Volvo increases the knowledge in 3DP the company would be able to control the process of using 3DP. According to an interviewee working with technology strategy and innovation, in a best case scenario, this could decrease the lead time of producing a part by 3DP to approximately three to four days; one day for design, one day to print and one day for finishes and quality checks. However, when such a best case scenario can be reached is dependent on the Volvo Group's strategy. Secondly, Volvo needs to have 3DP capability in place, either internally or externally. For external capability, an idea is to have machines at suppliers dedicated to Volvo. It is also important that the equipment and process used are quality assured in order to keep at least the same quality of parts compared to when using current manufacturing techniques. It is of crucial importance to maintain product quality in order not to dissatisfy customers or violate safety legislations. Furthermore, the supplier which Volvo works with is mainly working with plastics, even if the metal part of their business is expanding and developing. This results in constraints.

Mapping of suppliers is already being performed by the company. That Volvo has found only one 3DP supplier producing quality certified plastic parts is also considered as a constraint. It is important when looking into suppliers to ensure the capacity of producing fully functioning products that are certified according to standard. Today, this is a limitation in the business where prototypes are more common. Additionally, the aforementioned CAD-files need to be of duplicate versions, one for existing manufacturing technique and one for using 3DP.

The challenges for implementing 3DP above are summarized in Table 2. The challenges initially mentioned by an interviewee working with innovation framework program coordination and as a project leader for emerging technologies, have been supported by other interviewees. In addition, a challenge in a long term perspective is the protection of IP. When printing products become more common the possibility to print a wide range of products to a lower cost with a short lead time can become a threat to Volvo in the aftermarket.

Table 2: Main challenges for Volvo to implement 3DP

1. Lack of internal competence
2. No 3DP capability in place
3. Uncertainty regarding quality assurance
4. Design for 3DP
5. Protection of intellectual property

4.7 Collaboration with 3DP suppliers

In order to complement what has been written in the literature, two 3DP suppliers were contacted to get primary and updated information of the current state in the 3DP industry. The contacted suppliers are currently collaborating with Volvo regarding 3DP in the aftermarket and have provided information regarding both the current capacity and the future possibilities for the automotive aftermarket. The suppliers have global presence, providing customers with 3D-printers and products. Additionally, both companies have positive future aspect, where one has a planned expansion and the other one sees the potential for expansion considering the evolution of 3DP on the market. The contacted companies answered questions regarding 3DP and its potential in the automotive area. The questions can be found in Appendix II. The main findings are presented below.

Regarding the production capacity, which usually is discussed as an issue for 3DP, the answer is a bit unclear. When it comes to cost, lead time and production volume these factors are highly dependent on the product that is going to be manufactured and the post processes needed for the specific product. One approximation for the manufacturing is however 2-10 weeks. The size constraint as it is today for the suppliers are approximately 275*275*420 mm for metal manufacturing. Regarding the production volume, the highest potential is seen to be in the high end segment where the production volume is quite low, at least for the automotive industry. One of the companies says that volume wise smaller parts are produced in volumes of 1000-10000 pieces, while larger parts in 10-100 pieces. The future prospect is however that the machines will be able to produce bigger object and at a faster pace.

When comparing 3DP to traditional manufacturing methods, 3DP can be seen to have advantages in certain environments. One advantage is the functional benefits that can be achieved with the technique. Using 3DP can enhance the flow and thermal properties as well as optimize the weight. Another advantage mentioned by the suppliers are for complex parts, where 3DP can provide higher flexibility in the manufacturing.

Drawbacks with regards to the automotive industry are however also mentioned by the suppliers. Except for the limitation of products that are possible to print another one complicating the implementation in the automotive industry is the need for additional processes for completing a part. For example, polishing and quality checks are often required and a newly printed product is rarely adequate for end use. Another important aspect the company considers regarding the use of 3DP is to have a total cost perspective and the potential for each case is heavily relying on this.

The companies' main target customers are businesses, even if one of them does not rule out consumers as a customer group. The focus, as supported by the theoretical framework, has initially been on the aerospace industry but now the involvement in other industries such as automotive is increasing. When it comes to the service provided by the companies the offer differs a bit. One of the companies starts the process at the receiving of the drawing and provides the customer with the cad file and the part. The other company has a more complete offer where the involvement is from the production of the powder to the manufacturing and packaging of the 3D product. In this scenario, the collaboration between the actors is not a necessity, even if it is a possibility. For the company who mainly provides the part, collaboration is encouraged.

4.8 Swerea

In order to get a deeper understanding of the 3DP technology and complement what has been written in the theoretical framework a study visit at Swerea IVF was performed. The study visit included a presentation and discussion regarding 3DP as a technique as well as a visit to the workshop where 3D-printers and 3D-printed products were described and presented. Swerea is a Swedish research group working with industrial development and sustainable growth. Swerea is working in several different areas regarding material, production and product development. One area where Swerea is providing services and competence is 3DP. The involvement is during the entire chain, from the 3D modeling to the control and check of the complete product (Swerea, 2016).

When it comes to 3DP Swerea IVF is mainly focusing on four areas. These are design, material development, printing and quality control. These are all areas that currently are important to develop in order to be able to use the technique in production. One of the most important areas is the quality control, especially when it comes to high performance parts, and this is also something that today is quite uncertain.

What previously has been found to be suitable parts for using 3DP is also supported by Swerea, who find the urgent and emergency BORs as “spot on” regarding characteristics. I.e. slow moving, low volume, expensive or crucial parts etc. Additional characteristics mentioned suitable for 3DP are customized, interior and lightweight products. However, when 3DP can be used is extremely case dependent, both regarding product characteristics and when it comes to be economically and environmentally beneficial. In a life cycle perspective, the case is for example dependent on required production volume and the tools needed for producing the parts using traditional manufacturing technique.

There are some practical difficulties that need to be taken into consideration if adopting 3DP. Apart from the need of a printer there are several factors impacting how to produce a good part. There are three main steps; pre-printing, printing and post-printing. The pre-printing steps include the activities before the actual printing, i.e. design of the CAD-file, choice of material and deciding how the printing should be done, for example which support structure etc. Support structure is needed for different reasons, it is used in order to enable more geometrical shapes and avoid for example bending. Overhanging parts of the printed product is not possible without a support structure. When this is decided the actual printing can begin. The printed product is of course impacted by type of machine and ingoing material but also the operator and his/her knowledge and competence. The post-printing step includes the activities that are required in order for the part to be ready to use. This can for example include polishing or quality checks etc. As the technique looks today, the 3DP process is usually not quality assured and when it comes to high performance parts, this means that each individual part needs to be quality assured. Since post processes usually are needed, 3DP should, if compared to a traditional manufacturing technique, be compared to the casting or forging part of production. It is for these steps lead time can be cut, especially in small scale production.

The time to 3D-print a part is dependent on which resolution that is used, i.e. the thickness of each layer. The resolution affects the print time more than for example the size of the object. Set-up times also need to be included when calculating on the lead time. The set-up times can differ from a couple of hours to a day. Furthermore, to print several products with 3DP does not need to take longer time than printing one product. This is due to that if several products can be fitted on the production plate in the 3D-printer these can be printed at the same time. This is also beneficial from a cost and an environmental perspective. Additionally, the excess powder used in production can be reused. However, there is an uncertainty regarding how many times the powder can be reused since the material properties changes. The metal powder needed for printing a car is estimated to 400 kilos and the cost for steel powder is approximately 500-1000 SEK per kilo.

Powder supply is another issue mentioned by Swerea. There is currently no material that are designed for 3DP as a production technique and at the same time, the powder suppliers do not have the capacity for providing the powder if the market expands. Most of the metal powder suppliers today are aiming for the aerospace and medical industry which leaves the automotive industry in a position of lower priority.

Another drawback with 3DP is also the lack of design rules. This is due to that the technique today still is in its development phase. What actually is possible to 3DP is today not clear. When it comes to spare parts, these limitations are quite restrictive. Especially since the design freedom for existing spare parts are limited due to the fact that the parts need to fit existing vehicles. Therefore you cannot use the design freedom connected to the technology. For the future, if design for 3DP could be applied, this would increase the potential to a large extent. However, the development is constantly moving forward and the possibilities are increasing. The development is furthest in plastic parts, where speed and size are considerably larger than in for example metal. Even so, 3DP is mainly seen as a complementary technique to the traditional ways of manufacturing today. One example, that also is predicted to be more developed and used in the future is the integrated machines, where 3DP is used together with another technique, for example milling.

4.9 Main findings

3DP is considered as strategically important for the organization. Volvo is currently in a state where they are exploring the technology, hence the many initiatives within the organization, and building internal knowledge. Volvo collaborates with 3DP suppliers in order to be in the forefront and investigate how 3DP beneficially can be used at Volvo. Volvo has identified obstacles that need to be overcome in order for implementing 3DP in their business.

The answers from the 3DP suppliers are consistent with what has been written in the literature about 3DP. The suppliers confirm and highlight the benefits of 3DP related to flexibility and the possibility to print geometrically complex parts. They bring up the limitations regarding for example materials and dimensions and provide information on what is possible to 3D-print at the moment. Furthermore, both the suppliers and Swerea confirm what is written in the literature about that 3DP is not a complete solution that can replace all other manufacturing techniques used. Swerea further explained that 3DP is still in its development phase and no general comment regarding when 3DP is favorable can be given.

Additionally, the answers from the two suppliers complement the in the theoretical frameworks earlier mentioned trends with information about the companies’ positive outlook on the future and expansion plans. The suppliers also explained who they target and what they offer which is important in order to provide a recommendation for how 3DP can be used for BOR today.

5. Analysis

In the analysis the research questions will be answered. The analysis is based on the theoretical framework and the empirical findings. Research question one is described first and also forms a basis for the two following questions. Research question two and three also covers a case study which is used as a representation for the possibilities using 3DP for BOR.

5.1 Research Question One

In what context does 3DP, as a manufacturing technique (spare part provider), need to operate and in what situations can it be used to its highest potential in the BOR at Volvo?

Similar definitions of BOs to the one that Volvo uses today are also found in both theory and at UniCarriers. BO is a status of an order where there is no instant availability. This means that BOs are an issue that occurs due to that 100% availability is not possible. The theory however, states that the BOs are orders that the customers are willing to wait for some time in order to receive; it can be argued that otherwise the order would not be placed at all. Even so, how long time the customer is willing to wait is dependent on the criticality of the order. BOs or level of availability affect the customer satisfactions to a large extent, in the automotive aftermarket this is of high importance since the vehicle up-time is crucial for the customers (Freichel, 2010). The connection between BOs and customer service is also supported by Deghedi and Ibrahim (2013) that states that BOs are a measurement of the quality of the customer service for a company. The current situation at Volvo is that the importance of BOs is realized and considered as an important area to improve. Continuously improving the BOR is also prioritized.

BOs at Volvo today occur due to several reasons. The planned availability of 94% results in 6% of no instant availability. Orders that are solved the same day are still registered in the system as BOs however they are not considered as BOs by Volvo. This is not completely in line with the stated definition and could be considered as a cause for confusion. The interpretation of when BOs occurs has been seen to be a bit different during interviews; even so there has been no indication that it has been a source of confusion for the interviewed people. The reasons behind the BOs at Volvo are in alignment with the ones stated in the theoretical framework by Deghedi and Ibrahim (2013). There are both internal and external causes behind the BO. Some reasons can be related to the nature of the environment which is the automotive aftermarket. According to Lengu, Syntetos and Babai (2013) the intermittent demand impacts the possibility manage the inventory and material in an efficient way negatively. Freichel (2010) also mentions the high number of spare parts that are required as a complicating factor. For example, Volvo provides their customers with spare parts for at least 15 years, which means that old parts, that no longer are in production still need to be provided. This scenario for spare part management is described by Cohen, Agrawal and Agrawal (2006) who also describes the aftermarket SC as more complicated than a manufacturing SC overall. In conclusion the BOs occurring at Volvo are not seen to be anything out of the ordinary, the environmental circumstances and the tradeoff between cost and availability is common in the industry.

Since breakdowns, as it is today, cannot be scheduled in advance the reactive process needs to work in a fast and efficient way. Volvo has recently introduced a structured way of recovering BOs. This standardized way of working is based on the BO wheel. When a BO occurs, a checklist of actions should be followed, designed after brand and situation. This checklist is deemed as a suitable tool for this purpose and can if used, be seen to reduce time and errors in the BOR process. However, few employees handling the urgent orders follow this standardized way. If Volvo uses the best practice approach is difficult to assess since the theory on the subject of handling BOs is limited. Nevertheless, when comparing to UniCarriers, Volvo has a more structured way of working. The impact of the BOs on the customer satisfaction cannot be disregarded. Therefore, is the lack of theory on the subject puzzling. An underlying reason for this might be that due to that the BOR is a reactive process and during the literature review more research in the area of a proactive approach has been found, i.e. to avoid the BO which in this thesis is out of scope. This results in the impression that it is currently a more popular approach for researchers. Additionally, BOs can be seen as a sensitive subject for companies to share information on, since in an ideal world, BOs would not occur. However, the BOR process at Volvo is seen as adequate, since the target levels are usually fulfilled.

The complexity of the aftermarket SC also results in higher requirement on the distribution set-up. Since the lead time for BOR is important, the precondition for the distribution set-up is that the flexibility and responsiveness needs to be high. It is also important to consider that the distribution set-up for the aftermarket needs to be able to handle a lot of different things (Cohen, Agrawal & Agrawal, 2006) and even if there is a difference in need between the brands and regions at Volvo, a similar distribution set-up is used. The definition of an agile SC by Constantino et al (2012) seems beneficial in this setting. Christopher (2000) further supports the suitability of an agile SC to an environment similar to the automotive aftermarket. Volvo's current distribution is considered to be quite responsive, for example the use of SDCs makes the distance to customer shorter and impacts the lead time positively. Furthermore, they are able to reach their set target of 94% availability and also provide most customers with important products within the set timeframe for BOs which makes the current distribution perceived as good enough. Since being agile in an unpredictable environment is beneficial it is important for Volvo to be responsive but without tying up too much capital. Therefore, materials management is of importance in order to reduce cost and create stable processes (Vrat, 2014). Vrat (2014) also stresses the importance of a coordinated material flow, especially for companies present on a global market, such as Volvo.

The communication is also pointed out as an important part of being agile (Christopher, 2000). Volvo currently uses a lot of different IT-systems and the information sharing and communication is restricted due to this. Visibility is also considered as a SC challenge by Rushton, Croucher & Baker (2014) which seems to be the case also for Volvo. The forecasts today at Volvo are based on historical data, which seems to be a common way of forecasting spare parts since this also is the case at UniCarriers. UniCarriers does however have a higher level of transparency in their BO handling, where the system used are visible to more members in the SC. In conclusion, Volvo seems to have a distribution that can handle the uncertain environment adequately, even if there is room for improvements. The different warehouses handle different requirements where the SDC are mainly used in order to create a market sensitive structure. However, being agile is also costly; the closeness to customers with more warehouses also increases some of the materials management costs mentioned by Vrat (2014). Additionally, by increasing the transparency in the structure the responsiveness is believed to be improved further, and this is also something that Volvo is working on. Nonetheless, the circumstances of the Volvo automotive aftermarket make an entire agile structure difficult to achieve today, due to several reasons. For example, most of the current manufacturing techniques do not enable a fast one-piece production for on-demand production. Additionally, the current production techniques are set at certain locations, which means that a certain transportation lead time is required. The cost related to increased number of warehouses to achieve closeness to customer as well as small piece production is something that can be solved with using 3DP.

The customer satisfaction is a prioritized area within the Volvo Group and BOR is, as mentioned, closely related to this. In order to handle the BOs as fast as possible Volvo is taking several actions to solve the order and at the same time reduce lead time. The actions, however usually result in disadvantages, such as increased cost or environmental impact. How much time and effort that are spent on different BOs are related to the criticality, and the higher priority the order has, the more resources are spent. In order to be able to weigh the cost and service level the orders are categorized. This is important since it reduces the risk of spending more money than the customer requires (Rushton, Croucher & Baker 2014). However, even if Volvo has a clear categorization of BOs the placement of orders in the wrong category has been an issue in the past. The trend has been that the dealers are exaggerating the level of criticality since the current system is not trusted. Action is however taken in order to increase the trustworthiness of the system. During the interviews the customer satisfaction level does generally not seem to reflect the KPI measurement to the same extent. Several people perceive the customer satisfaction as low when it comes to BOs. One explanation can be that the availability is something that customers take for granted, and when the BOs situation occurs, the trust is already damaged. The patience from the customers' side is low, especially in a VOR situation. Additionally, the previously mentioned limited transparency and communication are believed to add to the low trust since the ETA is from a planning perspective of high importance when scheduling reparations for the dealers. By using 3DP, ETA could be more exact, assuming that Volvo has own 3DP capacity. This since the lead time is easier to assess for fewer steps of production. The overall assessment regarding the customer satisfaction is that it is a prioritized area where a lot of effort is put. However, the outcome is that the resources that are actually put in might not reach the customer to the extent that is possible. It is important to make the customers aware of how the work is proceeding, perhaps by better communication and information sharing. As it is today, this needs to be improved since the systems used do not enable this. However, that Volvo is prioritizing the customer satisfaction is good, since according to Phelan et al (2000) this is a way to distinguish the company from others. It can also be useful to create long term relationship and enhance the relationship between two actors (Dombrowski et al, 2011), which is important in order to take advantage of the vehicle's entire lifecycle.

The difference in perceived customer satisfaction and the actual BO KPI, which is supposed to be a service measurement in lead time, might not be an uncommon situation since one issue when it comes to service levels is that the companies struggle with defining what it actually is (Rushton, Croucher & Baker, 2014). This can make it difficult to evaluate and follow up the measurement in order to see that if performance is adequate. The service measure is however deemed as relevant since the focus on lead time is also what is most important for the customer. The lead time measurement is also used at other companies such as UniCarriers. Additionally, the measurement differs from segments and brands, which is supported by the literature also an important aspect to consider. Overall, the target levels are set to a reasonable limit that are achievable and accepted by both customer and Volvo. However, one of the regional areas has never reached the target, which indicates that this might not be a suitable target or measurement. Furthermore, the measures fluctuate considerably, due to different reasons, which also make the measurement increasingly difficult to assess. On the bigger markets such as EMEA and AMERICAS the measurement is more stable. If BO KPI is really a customer service measurement can on the other hand be discussed. This since according to Bergman and Klefsjö (2010) it is not possible to increase the satisfaction by a basic service, i.e. a service that the customer expects to receive from the beginning. The BO situation can therefore be seen to not increase the satisfaction but only lower it. Another drawback with the BO KPI is that it does not take loss of sales into account. I.e. if an order is not placed due to that there are no instant availability, this is not measured or evaluated.

Empirical findings have shown that 3DP is a prioritized technology at Volvo. This is considered as wise since 3DP is expected, both in the literature and by 3DP suppliers, to have a bright future in the automotive industry. Gartner (2014; a, 2015) believes 3DP has reached the slope of enlightenment and is entering the mainstream phase in the adoption cycle. The future possibilities and potential benefits of 3DP related to supply chain is further recognized by multiple authors (Gartner, b, 2015; Giffi, Gangula & Illinda, 2014; Mohr & Kahn, 2015; Sasson & Johnson, 2016; Srivatsan & Sudarshan, 2016). Information from 3DP suppliers has also complemented what is written in the literature and from information received it can be determined that suppliers have a positive outlook on the future.

From previous 3DP initiatives at Volvo it is regarded that Volvo is currently in a state where the company is exploring the technology, which suggest that Volvo follow path I in the framework by (Cotteleer & Joyce, 2014). It is recognized by Gartner (2014) that it can be hard to find a profitable area of use for emerging technologies. However, Volvo has now identified the aftermarket as a strategic segment for which 3DP can be used and launched initiatives to investigate this segment further. Previously Volvo has mainly used 3DP for prototypes and customized tooling, which has proven to reduce lead time and tooling costs. This is also supported in the literature by Giffi, Gangula and Illinda (2014) and Stratasys Ltd. (2015). To make use of 3D-printed tools for solving BOs is therefore an application that could improve customer satisfaction, which is also something Volvo has started to investigate.

The life cycle perspective is an approach that Volvo uses when it comes to segmentation of products. By including the life cycle perspective in the segmentation Volvo has done improvement in cost reduction and availability. The improvement might be related to that the segmentation can be used to meet some of the challenges in the aftermarket SC, such as inventory management and cost reduction. The life cycle perspective is therefore believed to be a large part of creating an optimal segmentation. If looking at the potential for 3DP from a lifecycle perspective, there is potential through the entire life cycle. In the phase out phase of the lifecycle the availability is set lower i.e. there are products you do not want to keep in stock. Due to the lower set availability it can also be reasoned that in percentage more BOs will occur. Furthermore, there is a higher likelihood that these old spare parts have suppliers that might not exist anymore or lack the tools to produce the spare part. One drawback with old parts is that there are less existing drawings of the parts, which complicates the making of the CAD-file. Potential for 3DP can also be seen in the initial phase of the product life cycle. This since there is an uncertainty when the demand for a new spare part will start to increase which increases the risk for BOs. 3DP could help balancing risks in the initial forecasting in this phase. The use of 3DP allows for taking higher risks in the forecasting in order to avoid high inventory costs since it can serve as a backup solution to solve BOs quickly if BOs occur. In the prime phase of the life the demand is higher, however as long as the volume for each order is low the potential for 3DP can be seen here as well. One issue is that the lead time for using 3DP is often too long for these component, since in the prime phase, the customer expects higher service level.

Potential can also be seen for expensive and low volume components, which is identified by Giffi, Gangula and Illinda (2014) as possible application for 3DP. This is also supported by the 3DP suppliers. BOs usually have these characteristics and BOR is therefore seen as an area with high potential. Swerea further supported this argument by stating it as a “spot on” area of application. In the current situation 3DP is costlier than conventional manufacturing techniques, at least when it comes to large scale production. The powder used for metal printing is expensive and according to Swerea a good application needs to be found in order to see benefits in terms of cost. Furthermore, 3DP has better potential to be justifiable for small scale production, since for larger batches gains from economies of scale can be achieved and then conventional manufacturing techniques become more attractive.

Volvo’s collaboration with several of the leading 3DP suppliers is considered to be valuable. This is supported by Gartner (2014) that says that collaboration is important in order to stay ahead and get access to valuable information. There are currently different methods of the technology on the market (Gibson, Rosen & Stucker, 2015) and the suppliers differentiate themselves through specializing on different methods. It is therefore of importance to engage with several suppliers in order to see which of the methods that will be most useful for automotive applications. At the moment there is no standard method and the technology is constantly developing. In the present situation it is therefore important to follow the development of 3DP in close collaboration with suppliers. With close collaboration Volvo also have the possibility to influence the suppliers and make them consider and understand Volvo’s needs and expectations. Information received from 3DP suppliers also shows that the suppliers also see potential benefits for 3DP in the aftermarket, but what the suppliers are offering differs. This is an additional reason for Volvo to collaborate with several suppliers in the current situation.

As identified by Volvo there are challenges and certain limitations in the technique. A precondition for Volvo to be able to use 3DP in the BOR process is to overcome these challenges and how this should be done requires further investigation. Even though, 3DP brings benefits such as freedom of design, reduced production steps and weight reduction, which are supported both in the theoretical framework and by 3D-printer suppliers, there are limitations in the technique regarding for instance materials, dimensions, surface, quality assured production etc. However, 3DP is a hot topic and ongoing research result in advances in the 3DP area regarding these limitations. Still, in the current situation all of Volvo's parts are not possible to print and 3DP is additionally not suited for serial production. Furthermore, the speed of the production technique has been brought up by Babu et al. (2015) as a main limitation for 3DP. The speed for producing an item is in general slower than for traditional manufacturing techniques. However, the flexibility that 3DP provides can result in higher speed in certain situations. For example, lead time can be shortened if the part is printed closer to the customer or if 3DP can replace multiple other production steps. As it is today, the speed limitations make 3DP more beneficial to use for BOR in the aftermarket than for mass-production.

To solve BOs as soon as possible is of high importance in order to increase customer satisfaction. Based on this, lead time is important to consider. The shortest lead time would be achieved if spare parts are printed on-demand as close to the customers as possible. This advantage of 3DP, mentioned by both Giffi, Gangula & Illinda (2014) and Gartner (b, 2015), could therefore be considered as the most valuable in a BOR context. To produce products on-demand cannot only reduce lead time but also reduce the need of inventory in the supply chain (Giffi, Gangula & Illinda, 2014; Mohr & Khan, 2015). In Volvo's case, the target would be printing at the dealers since according to a business consultant the motto for 3DP is "print on-demand where the demand is". However, from information received, this is not possible in the current situation. This is due several reasons.

Firstly, as the technique looks today, it is not quality assured which is a requirement for ensuring the quality for Volvo products. Additionally, printed part requires post processing, as mentioned by Srivatsan & Sudarshan (2016), Swerea and by 3DP suppliers. The post processing can be different dependent on printed article. This would require resources accordingly at the dealer location. To have production equipment at each dealer would not be economically justifiable since Volvo has over 3000 dealers with different ownership which makes it difficult to assess where to place the printers. Swerea also highlighted the importance of the operator's knowledge and skills. To 3D-print at the dealers would require 3DP knowledge at all these locations, something that is not available today. Additionally, printers at the dealers increase the risk of IP theft, which is mentioned as a risk by Giffi, Gangula and Illinda (2014) and can result in financial loss. This risk is seen to be higher since more people will have access to the files.

Furthermore, the Volvo Group needs to take a decision regarding if to invest in own 3D-printers or if to buy the service from 3DP suppliers. Since there are different methods within 3DP this means that several different machines need to be bought and placed at the dealer location in order to be able to print different products. This would tie up a large amount of capital and is not considered economically justifiable. If Volvo instead chooses to buy the service, it is not possible to print at the dealer and the possibility to print close to the dealer location will depend on the supplier's geographical spread. The contacted 3DP suppliers claim to be global. However, in the current situation only one supplier has quality assured manufacturing and this only at one place in the world, which makes the target to have 3DP at the dealers not reachable today.

To summarize, in order to answer the first research question it is important to take into consideration the factors that affect the usage of 3DP in BOR. First off, BOs in the aftermarket occur and are planned for. There are several different reasons behind why BOs occur, however there are no solutions today that will eliminate BOs in a favorable way, which stresses the importance of improvements in this area. A precondition is that when a BO occurs, the customer is willing to wait to get the part, even if it is not appreciated. This is an important aspect since 3DP requires a certain lead time. The usage of 3DP can however decrease the lead time from several of the scenarios today, which also will decrease the negative effect BOs have on customer satisfaction. This is a precondition for Volvo to introduce the technique in the aftermarket since customer service is of high importance. The technology today is seen to have a bright future with high potential, especially in segments like the automotive aftermarket. This is due to that the drawbacks that affect the technology today are not as limiting in this segment, but the benefits are still achievable. What needs to be considered is where and when to adapt the technique, since 3DP is expensive the case needs to be considered carefully. The preconditions in the BOR at Volvo are deemed mainly positive based on the previous analysis and in the two following research questions it will be investigated how 3DP can affect BOR at Volvo both today and in five to ten years.

5.2 Research Question Two

How can 3DP affect the current BOR process at Volvo in terms of lead time, cost and environmental impact?

A case study is, as mentioned, a good way of providing insight to a topic that is not yet quite understood. It can also be used to describe an event in the current situation as well as from a future perspective which makes a case study useful in order to answer the second and third question of this thesis. The case study will therefore include calculations on the three measurements defined in the question, i.e. lead time, cost and environmental impact.

Based on the noted preconditions at Volvo, the case chosen to investigate is where the result is predicted to be significant as well as reliable. The case study is regarding the North American market and the brand VCE. The reasons behind this area of investigation are several. First off, the measurements for this market are stable, which is a precondition in order to be able to compare and evaluate the result of the case study. Additionally, according to Rushton, Croucher and Baker (2014) long transportation distance is an issue in the US and the transportation costs are affected by high fuel price and distances. This is also true for the current distribution setup in America, which provides good chances of lowering transportation costs. If 3DP could be applied closer to the customers, which supported by both Mohr and Khan (2015) and Srivatsan and Sudarshan (2016) shorter distances is a possible advantage of the technique. Additionally, closer distances can increase flexibility in the SC since it can reduce the lead time, which is according to Christopher (2000) is suitable in a demand uncertain environment. Another reason VCE is believed to be a suitable area of investigation is that according to a theoretical optimization specialist, VCE has a large number of spare parts that need to be provided, at the same time as the lifetime for the vehicles is long. This means that VCE need to hold large amount of spare parts in inventory, which increases the material management costs (Vrat, 2014). Additionally, there are many slow moving parts which also result in tied up capital in inventory due to lot sizes and availability requirements. Regarding the technology itself, the North American market is a suitable option as well. This since a large part of the available suppliers of 3DP is located in America according to Swerea. Additionally, USA is the country which leads the world in 3DP innovation and adoption (Frost & Sullivan, 2015).

The distribution set-up for VCE in North America is described in Figure 20. There are three DCs, one CDC in Byhalia and one RDC in Reno. There is also a DC located in Columbus, however this DC is moving to Byhalia and are now only containing slow moving parts. In Byhalia the inventory contains medium and fast moving articles. Approximately 50-60% is sourced from outside of North America, where the largest amount arrives from Europe or Korea. The parts are arriving at the CDC and are distributed to where it is going to be stored.

Figure 20: VCE’s DCs in North America

To provide customer with spare parts there are 193 VCE dealers located in North America. The geographical spread, provided by the theoretical optimization specialist working with VCE, is summarized in Table 3.

Table 3: Dealer distribution in North America for VCE

North America	Dealers
Canada	43
Central	46
East	52
Northeast	21
West	31
Total	193

The dealers have approximately 9-15% of the spare parts on the shelves according to the concept development manager. These are the fast moving products that are needed frequently by the customers. These are also the parts that stand for a large part of the sales. The rest of the parts are so called slow moving and transported to the dealers when needed from the CDC or RDC. Even if these less frequent parts contribute to a lower part of the sales, they still need to be kept in inventory and therefore increases the inventory related costs.

Figure 21 shows the total amount of urgent and emergency BOs for VCE in North America over a 12-month period. Based in this data, approximately 98,3% of the incoming BOs during this period were solved within the five days and therefore fulfill the BO KPI target. However, there are still BOs which are not recovered in several weeks, or even months. These, especially when it comes to emergency BOs are very costly for both Volvo and the customer. The data also shows that solved BOs are not always sent immediately when received at the DC, even if this does not affect the measurement, it affects the customer satisfaction.

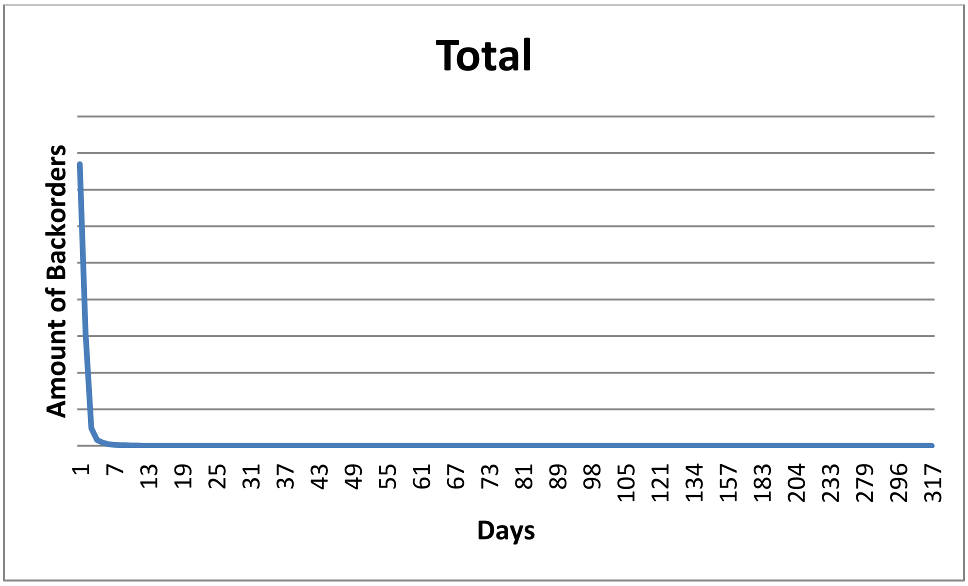

Figure 21: The total amount of urgent and emergency BOs for VCE in North America over a 12-month period

Due to the current limitations to the 3DP technology regarding the lead time, which is based on information provided by suppliers, the potential for using 3DP in the BOR is seen to be beneficial in those cases where the BOs have been longer than 15 days (i.e. three weeks). Since in these cases, the lead time for using 3DP can compete with the traditional approach. Figure 22 shows the BOs remaining for 15 days and longer.

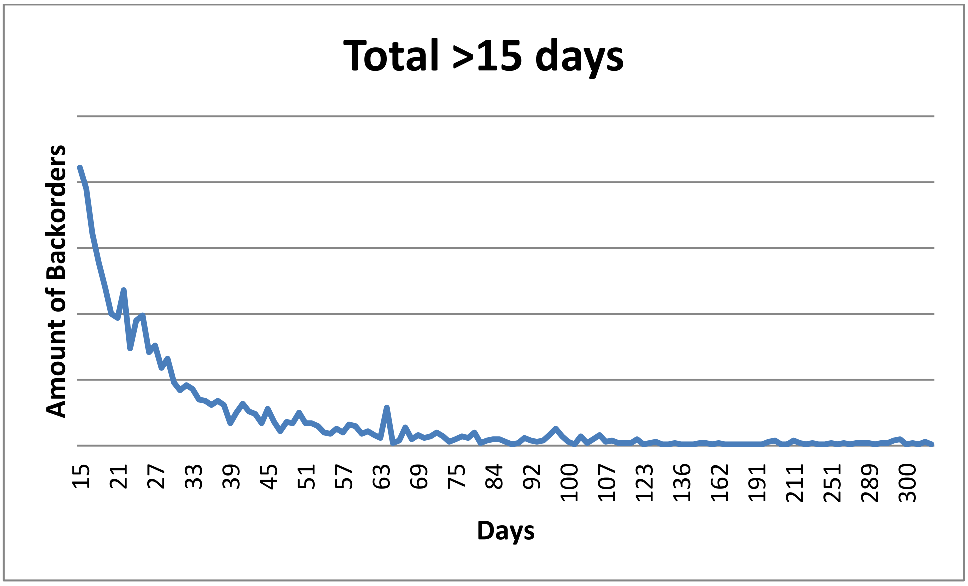

Figure 22: The amount of urgent and emergency BOs older than 15 days for VCE in North America over a 12-month period

The lead time aspect is as mentioned based on current information from suppliers. This is however not the actual printing time, which is significantly shorter, but also includes waiting time and lead time for pre- and post-processes. This estimation is used since it is the information provided from several sources and regards the purchase of a product. If for example Volvo decided to buy capacity instead, the lead time can be less dependent on suppliers' estimated lead time per product. Since lead time is one of the main factors that impact the customer satisfaction when it comes to BOs this estimation from the suppliers is the first parameter when analyzing the potential for 3DP in BOR. The second parameter, which also is one of the investigated measurements, is cost. According to Giffi, Gangula and Illinda (2014) 3DP is suitable for expensive and small volume components, this since 3DP is considered as an expensive production technique with low capacity in production volume. The cost for 3DP is increased by high material cost, especially when it comes to metal as well as the time it takes for each product to be printed. However, there are situations where 3DP also can be beneficial in a cost sense. Even if the cost per unit for the most part is higher, there are other aspects affecting the total cost when it comes to BOs. These can for example be related to inventory carrying costs, transportations costs, handling costs, BO costs (virtual revenue loss for the customer), bad will, lot sizes, setup time, loss of sales etc.

The identified cost drivers are described in Table 4. By identifying the cost drivers for the BOs a comparison of the different scenarios can be performed, which means the current scenario with the use of 3DP. The identified cost drivers are based on information from interviews, the theoretical framework, previously performed work within 3DP at Volvo as well as existing total cost models used today at Volvo.

Table 4: Cost drivers impacted by BOR and 3DP

Direct Costs	**Indirect Costs**
Transportation	Inventory related
Order-handling	IT
Handling	Administrative
Manufacturing	Man-hour
Material	Maintenance
Product	R&D
Packaging	Bad will
	Loss of sales
	Customs

The main costs affected are the inventory and transportation related costs as well as the product cost per unit (purchasing price). The identified logistics costs related to the BOs are also the costs that, supported by Jonsson & Mattsson (2011) and Rushton, Croucher & Baker (2014) are mostly influencing when it comes to logistics. By using 3DP in BOR the logistic is deemed possible to change which will directly affect the logistics related costs.

BOs occur, as mentioned, due to the lack of the right product at the right time in inventory. However, BOs can also result in higher inventory. One reason can for example be due to minimum order quantities. If the quantity ordered is higher than the demand it result in excess inventory, if the pick-frequency for the particular article is low, the inventory can be carried for a long time and even lead to scrapping. Since BOs often are one or few piece orders this increases the likelihood of incurring inventory and thereby also inventory carrying costs. By using 3DP costs related to inventory can be reduced since according to Sasson & Johnson

(2016) and Giffi, Gangula & Illinda (2014) the required amount of inventory is lower. This can be linked to that 3DP is suited for on-demand production. Additionally, since CAD-files can be stored virtually, this can further reduce physical inventory and also according to Christopher (2000) increase the flexibility of the SC which is beneficial in both cost and service aspects. 3DP also makes it possible to print complex products and reduce the number of parts (Babu et al., 2015; Komenda, 2014). This will further reduce the need for inventory and thereby tied up capital.

When it comes to transportation costs 3DP also makes it possible to reduce the costs. This is mainly dependent on the possibilities to reduce transportation distances since according to Srivatsan & Sudarshan (2016) 3DP can be used as small manufacturers close to the end customer. Even though, based on the current situation at Volvo, this is not deemed possible today due to the reason mentioned in Chapter 5.1. Other factors are however also impacting the transportation costs and can have positive effect already today. If fewer parts are needed as mentioned by Babu et al (2015) and Komenda (2016) the transportation can be reduced since fewer transportations are needed from less suppliers. Another characteristic of 3DP products is according to Arcam (2016) weight reduction, which is an impacting factor when it comes to fuel usage and capacity utilization, which also affect the costs.

When it comes to order-handling the cost is deemed to be insignificant, since the time for considering using 3DP to solve the BO is neither time nor resource consuming. The handling time is case specific. Today, the distribution is set and will therefore form the base of this analysis. The assumption is that the article will take the same route through the distribution system and therefore the handling costs today will remain regarding load/unload points in the system. The same goes for the transportation cost, transportations distances and custom costs. The current distribution set up, with delivery from Europe, is used since according to investigation it is where the quality assured production is today. However, a mapping of suppliers has not been performed and therefore the case is based on this received information. When it comes to handling and packaging, 3DP could reduce the number of articles, and therefore require less need for assembly and packaging since there will only be one, already mounted product. Another important aspect to consider is the BO costs, related to revenue loss for the customer, which is seen to be able to diminish by using 3DP. Today these are mainly regarding the BOs that have been longer than 15 days, which according to suppliers are the current lead time. If reducing customer loss, this also has the possibility to reduce the risk of bad will for the company.

Due to the scope of this thesis the main cost differences, between using 3DP and the traditional BOR process, that have been noticed, can be related to the logistics. However, there are several aspects that are affected by the use of 3DP and when considering costs, manufacturing- and product costs are also deemed to be relevant to address. One is the product price per unit, which is believed to increase. This is based on the information provided by Swerea about higher material prices as well as the pre work needed for each article. For example, the redesign of the CAD-file and how to print take time and require resources. Post processes are, mentioned by Swerea, suppliers and Srivatsan & Sudarshan

(2016), usually needed which also result in additional costs. 3DP will also increase the pressure on IT since the CAD-files needs to be stored and distributed. Since fewer parts is mentioned as a possibility this can reduce the time spent by the purchasers, i.e. less time on sourcing (Giffi, Gangula & Illinda, 2014). In the current situation Volvo does not have own printing capacity and the reliance is on the suppliers, this result in that some cost benefits that can be connected to the manufacturing cannot be utilized. This can for example be reuse of powder and fewer resources such as fixtures machines (Srivatsan & Sudarshan, 2016). However, the supplier is more advanced in the expertise and capability, and therefore the service is considered worth paying for.

Since, according to Chopra and Meindl (2013) *"lead time is the gap between when an order is placed and when it is received"*, all activities performed in between that can contribute to the lead time needs to be considered in the case study. Based on empirical findings from the BOR process at Volvo, activities that generate lead time are considered to be order handling, sourcing, transportation and handling.

The order handling lead time can be considered to be the same if 3DP is used. The one handling the BO still have to go through the different options in the BO wheel to find a possible solution for solving the BO. However, regarding sourcing lead time, two of the main reasons for BOs found at Volvo are supplier delivery problems and supplier capability issues. Lead times related to these issues can be reduced with 3DP capability in place. Additionally, the sourcing lead time is expected to further decrease due to shorter manufacturing lead time with use of 3DP. As mentioned by Gibson, Rosen & Stucker (2015) and Srivatsan & Sudarshan (2016) 3DP can reduce the number of production steps needed. Based on this, if compared to traditional manufacturing, 3DP can reduce the lead time for manufacturing. The manufacturing lead time for 3DP might differ for the different methods of the 3DP technique and the material used. Swerea also mentioned that the speed of manufacturing is dependent on with which resolution one print. However, today the capacity at suppliers is low which generates waiting time. The waiting time is included in the 5 to 15 days lead time for sourcing. The difference in lead time between the current BOR process and if using 3DP can be seen in Figure 23 and 24.

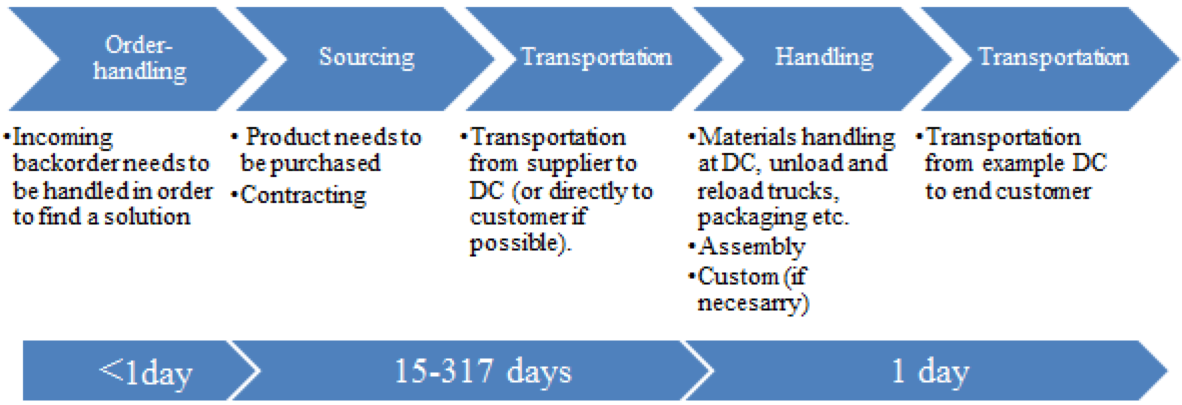

Figure 23: Illustration of BOR steps and current lead time for long term BOs.

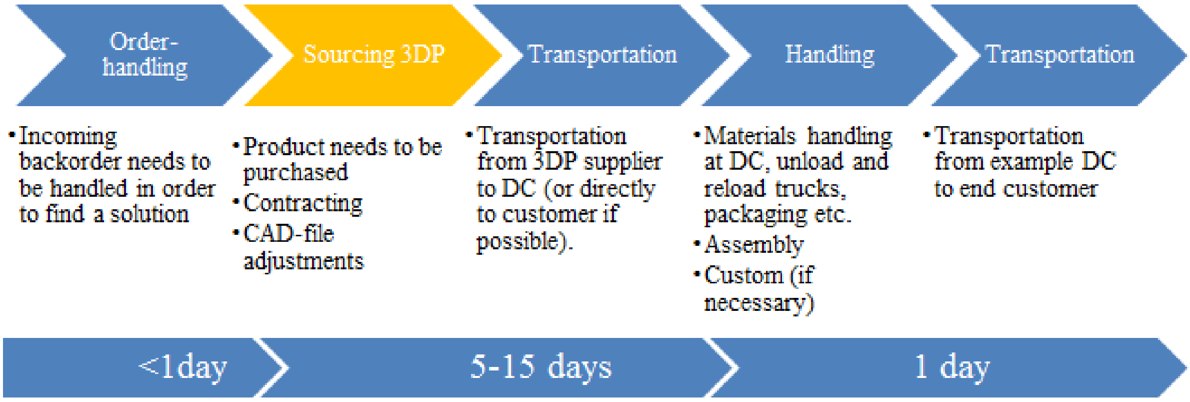

Figure 24: Illustration of BOR steps and current lead time for long term BOR if using 3DP.

Environmental impact for the scenarios chosen in the case study is mainly related to transportation. At Volvo, rush transportation by air is mostly used to deliver urgent and emergency BOs. Air transportation is the transportation mode that, mentioned by Jonsson and Mattsson, (2011) and Lumsden (2007), often is used to deliver time sensitive and emergency shipments. It is therefore assumed in the case study that deliveries are performed using this transportation mode. One drawback using this mode of transportation is, according to McKinnon et al (2015) that air transportation emits the largest amount of carbon dioxide per tonne-km. Volvo's choice to prioritize lead time for BOs is therefore contributing to the global footprint which is not in line with the Volvo Group's vision to *"become the world leader in sustainable transport solutions"* (Volvo, 2016) or the commitment to decrease the carbon dioxide emissions per produced unit from the Volvo Group freight transport with 20% until year 2020 (WWF, 2014).

As mentioned earlier, it is not believed that transportation distances can be shortened in the current situation. Therefore, there will be no significant decrease in environmental impact if introducing 3DP today. Though, according to Arcam (2016), 3DP has the possibility to reduce the weight of the produced articles. As mentioned earlier, this will cost the shipper less, but it can also decrease the environmental impact for transportation. This since less fuel is needed for a lower weight.

The environmental impact related to packaging is also expected to decrease. This since, as previously mentioned, 3DP can reduce the number of articles and therefore the use of wrapping material will decrease. 3DP is also considered to have high efficiency in material use (Srivatsan & Sudarshan, 2016), which is positive from an environmental perspective. According to both Srivatsan and Sudarshan (2016) and Swerea, the excess powder in the 3DP machine can be reused. 3DP can therefore decrease the environmental impact for manufacturing compared to other traditional manufacturing techniques. Additionally, if over sourcing due to minimum order quantities can be avoided this will also result in less scrap.

Based on the received data presented in Figure 22 there are 0,5% of the BOs that have been longer than 15 days. The BOs range between 1 day and 317 days. The potential virtual revenue loss for the customer, is for this data is around 100 00 000 €. This is based on a theoretical estimation made by Volvo for each BO. Assuming that all these BOs are printable and could be solved, the savings potential only in this area is high. Additionally, Volvo spends more on BOs than on ordinary orders due to the criticality. However, as it looks today, printing all these products is not possible, and due to the limitations regarding 3DP there are certain aspects to consider when deciding which BOs that can and should be printed. These aspects are based on the previous analysis and described in Figure 25. It describes the total amount of BOs and the limitations; it is not made to scale but aims to provide a conceptual illustration.

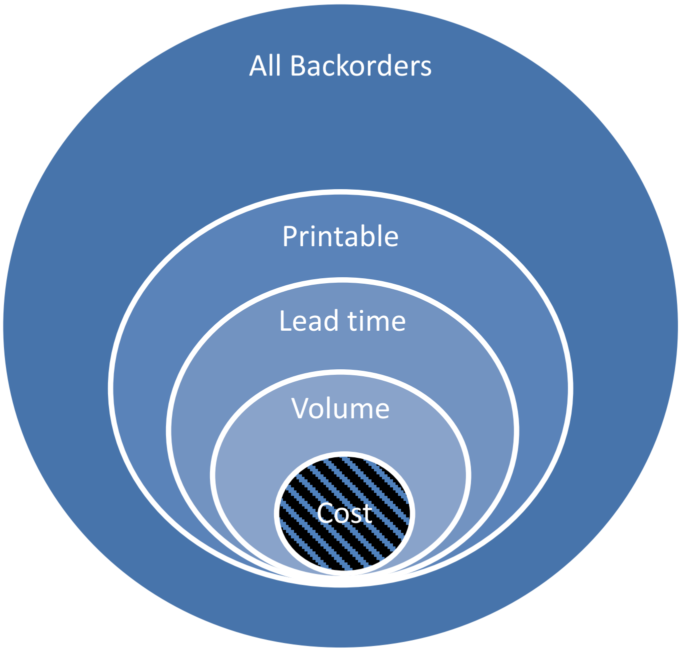

Figure 25: Aspects to consider when using 3DP

The main parameters that should be considered are; printability, lead time, volume and cost. The printability which is a precondition for using the technique is however is in this thesis out of scope and will not steer the result. The products investigated are therefore assumed to be printable. Printability also includes that the printed product is quality assured. The second parameter is lead time. Here the interval has been stated as between one to three weeks today, based on received information. Since BOR is lead time dependent, this needs to be the first criteria for the printable BOs to fulfill. If the lead times for using 3DP is shorter or equal to the traditional sourcing alternative the second criteria to consider is the volume. This is due to that 3DP is not suited for mass production (Frost & Sullivan, 2016). One example where it is not deemed feasible is in situation where the volumes are too large; consider initial forecasting for a high frequent product. 3DP has the possibility to cover for small deviations, however if the forecast is off by say 10% for a high volume product, this could probably not be solved with 3DP due to both production capacity and cost aspects. However, for BOs the volume is usually low, which also is one of the reasons behind the potential for 3DP. According to the data analyzed 62% of the BOs have the quantity one and 96% is below 10 units. The last criterion is cost. For BOs a higher cost is usually acceptable due to the severity of the situation for the customer; however, it is not solved at any price. With these parameters in consideration, the remaining BOs should be printed, which is the striped area represented in Figure 25. In time, the parameters can change, therefore the limitations in the figure should be continuously updated.

From the received BO data 15 products were chosen due to certain characteristics. The BOs were chosen with regards to weight, lead time, order quantity, and unit cost. These are the parameters, based on previous analysis, where highest potential for a case is seen. The data provided limited information and therefore the parts properties and drawings needed to be requested separately. When the properties and dimensions were investigated all of the chosen products turned out to be made of metal, which made the case limited to investigate a metal part. The product with highest potential was decided to be followed through the system.

The difference between the “as is” state and if using 3DP today has been seen to shorten the lead time but increase the cost per unit for the investigated BO. The environmental impact in this scenario cannot be deemed to change due to the same transportation solution for the different manufacturing approaches. The cost for 3DP is based on material cost and labor cost which according to Shapeways (2016) are the main posts for the product price when considering metal printed parts. Table 5 shows the difference in percent. The cost included in the calculations are purchasing price, transportation and handling costs.

Table 5: The difference between “as is” and using 3DP for one specific product (excluding inventory & inventory carrying cost).

	Cost for Backorder	**Lead-time**	**Environmental**
3DP Today	+ 28 %	- 63 %	-

As expected from the previous analysis the result shows increased product cost but decreased lead time. Due to the lack of plastic parts in the investigated data, the case only includes a metal product. However, if this instead would have been a plastic part the lead time and cost is believed to decrease. According to Swerea, the development is the furthest for plastics and the speed for printing plastic products is higher than for metal products. The volume of the printer is also bigger in plastic printing, which makes it possible to print larger or more products at the same time. By printing several objects at the same time, the cost per unit can be decreased. The souring cost could also possibly be decreased for a plastic part. According to Shapeways (2016) material and labor costs highly impacts the cost of 3DP. The material cost for plastics can be assumed to be lower than for metal. Additionally, post-printing steps can take longer time for metal products since metal can be harder to process than plastic. This results in higher labor costs for manufacturing metal parts.

If including inventory and inventory carrying cost for this case the total cost will however be lower for 3DP. Since the minimum order quantity in the traditional sourcing is ten as opposed to one if using 3DP the inventory related costs for the remaining nine products need to be considered. For this particular product the pick frequency is one per year, which means that the products need to be stored for nine years. If comparing the two scenarios for ten products, the result is 12% lower cost for using 3DP, even if the price per unit is higher. This is also assuming that the products are sold once a year during a ten-year timeframe. If the products are sold less frequently or needs to be scrapped, using 3DP the cost will decrease even more. If the demand for the product is higher, the traditional sourcing is more beneficial. Additionally, the risk of scrapping is eliminated when 3DP on-demand.

What also is important to consider when it comes to emergency BOs is the loss it generates for the customer. For this specific case the customer loss can be decreased with 27000 €. What should be noted is that the calculations are rough estimations based on information provided by theoretical and empirical findings. Due to that the cost and lead times for 3DP is very dependent on the specific part and the drawing of the part was not possible to share with a third party, this made the result rely on estimations as inputs. A generalization is even difficult for the experts in the area to assess, which makes the result more of an indication of direction rather than exact science.

5.3 Research Question Three

How can 3DP affect the BOR process at Volvo in five to ten years in terms of lead time, cost and environmental impact?

Within the 3DP area, a lot has happened in the last couple of years and a lot is expected to happen in the upcoming years. According to Gartner (2015), the technology is starting to become mainstream and high potential for the industry in the future is seen (Manners-Bell, 2014; Mohr & Khan, 2015). However, there are uncertainties regarding how the technology will develop in five to ten years and how this will affect cost, lead time and environmental impact.

As mentioned earlier in Chapter 5.1, in the current situation it is not possible to use 3DP at the dealers and also in five to ten years it is deemed as unlikely that this target can be reached. It is dependent on several factors, for example the development of the technology, Volvo’s strategic decisions and global spread of 3DP suppliers. In the future scenario it is deemed likely that 3D-printed spare parts can be produced or sourced regionally. For the case study this means that 3DP capability can be sourced at several places within North America. If Volvo prints the product themselves or buys the service is not deemed to affect the case result. There are however risks connected to both scenarios. If Volvo decides to invest in own 3DP capacity, the rapid development can outdate the machines and resources are required for increase internal competence. On the other hand, it can provide integration with the rest of the business that can be crucial for the future i.e. Volvo can update their manufacturing technique. If buying the service, Volvo also needs to consider the risk of IP theft which is considered to be higher since CAD-files need to be distributed externally.

It is hard to comment on how the difference in cost will be for 3DP in five to ten years compared to 3DP in the current situation. Development of technology can possibly be assumed to result in shorter the lead times for pre-printing, printing and post-printing. Then the costs related to man-hours for 3DP a product can be reduced. For example, the man-hours related to redesigning the CAD-files. In the future it can also be expected that the competition among 3DP suppliers will increase, which might lead to decreased costs for 3DP. Beyond that, it is hard to predict how the costs for 3DP will change in the future.

The products that are possible to print are believed to increase when considering the development of the technique. If looking at the parameters described in Figure 25 these are all deemed to be less restrictive in five to ten years than they are today. Increased quality assured production from more suppliers and larger dimensions and production volume will make the share of printable products increase. For BOs in particular the increased speed will be a main prerequisite for enlarge the share of printing BOs.

In the current situation quality assured 3DP has only been found at one of the 3DP suppliers contacted. Based on the positive trends for 3DP, the geographical spread of suppliers is expected to increase and it is believed that quality assured 3DP will exist in North America in five to ten years. In the case study this means that transportation will become domestic. Thus, the lead time will be shortened and the cost as well as the impact decreased due to shorter distances. The cost is an important factor when it comes to transportations since supported by Rushton, Croucher & Baker (2014) it stands for 49% of logistics cost. Transportation within North America can also be performed by road transportation, which can further decrease the cost and environmental impact, since this transportation mode is cheaper and emits less carbon dioxide per tonne-km.

If the positive trends of 3DP continue, it can also be expected that in the future, 3DP suppliers expand their offerings. It is therefore of importance to map 3DP suppliers and identity their offerings. It can be of value to create selection criteria in order to see with whom to establish relationships.

The lead time can further be shortened if the backordered spare part has been produced by 3DP before, i.e. it is not a first time print. This since some of the activities in the pre-printing step for 3DP then already have been performed for the first backordered part and do not need to be performed for the following. Once having created CAD-files adapted for 3DP it is important not to let these get into the wrong hands. The issue with IP has been brought up both at Volvo and in the theory by Giffi, Gangula and Illinda (2014). In the future to have to have clear contracts with 3DP suppliers can mitigate the risk of theft. Also, to have centrally controlled 3DP capability at the 3DP suppliers managed by Volvo can be an option. In the future the drawings of new spare parts might already be designed for 3DP. This will also reduce the lead time since there is no need for redesigning the CAD-file. Additionally, in the future new actual spare parts can be designed for 3DP from the beginning, which can also decrease the lead time. However, since the lifetime of a vehicle is longer than five to ten years it is unlikely that all Volvo spare parts will have drawings adapted for 3DP or be designed for 3DP by then.

The main difference in lead time for 3DP in five to ten years is expected to be seen in sourcing (see Figure 26). This since in the current 5 to 15 days lead time includes waiting time due to low capacity at the 3DP suppliers. In the future state this can be predicted to become one to two days instead. Additionally, with quality assured 3DP capability in North

America the transportation distance between Europe and North America can be cut. Order handling is expected to be the same.

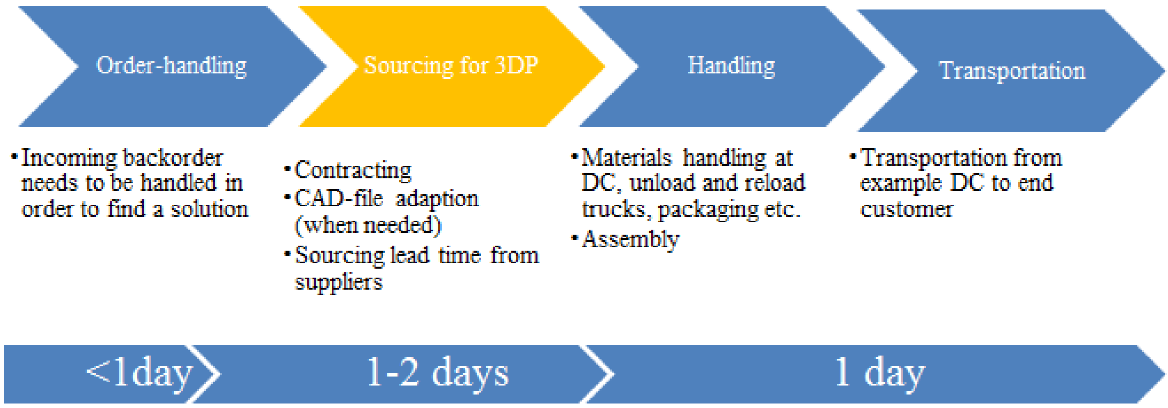

Figure 26: Possibility in 5-10 years if using 3DP in BOR

Future potential for the case described in research question two is considered as high based on the assessed differences are described in Table 6. The price of the article is not included since the assessment is difficult as it is today.

Table 6: Difference in lead time, environmental impact and customer loss of revenue for the case in five to ten years

	Lead Time	**Environmental Impact**	**Customer loss of revenue**
3DP in 5-10 years	-81%	-95%	-13000€

As described in Chapter 5.1, there is potential for using 3DP through the entire life cycle. Most BOs occur in the prime phase, which can probably be related to higher demand in this phase. In five to ten years, when the volume and speed restriction is believed to be reduced, the prime phase can be considered as an area where the highest potential can be seen.

In a large organization such as Volvo, for the future it becomes important to cooperate across borders in order to reach Path IV in the framework by Cotteleer and Joyce (2014). To reach Path IV, change in both supply chain and product is required. As mentioned, 3DP for BOR can highly affect the supply chain. However, to use 3DP to its full potential the benefits of 3DP such as customization, increase product functionality and low cost for increased complexity should be utilized. In the current situation the freedom of design is not possible to achieve to the extent that it could. The parts needed today have set design and properties in order to function in the existing vehicle. In five to ten years it is therefore deemed possible for Volvo to reach Path II if implementing 3DP in the BOR process. However, to reach Path IV in the upcoming years Volvo must continue to explore 3DP for applications other than BOR as well.

6. Discussion

The outcome of the thesis can hopefully provide Volvo with guidance of how 3DP will be approached in the upcoming years. The thesis serves as a pre-study which aim to provide Volvo with more knowledge. Due to the many uncertainties regarding 3DP both in the current situation and in the future, it is difficult to give an exact evaluation. The recommendations are therefore of conceptual nature. The reader is further encouraged to put emphasis on the provided recommendations rather than on the numerical results in the case study. The calculations serve more as an illustration of a possible scenario of where 3DP can be used today rather than a proof of concept. There are limiting factors in the case study which should be noted. Firstly, the lead time used for calculations has relied on estimations from suppliers. It is however difficult to assess a lead time for each specific case, and how the suppliers have estimated a general lead time is not clear. Secondly, more than one product should have been calculated on to be able to use the result as a basis for decisions. Additionally, only a metal product was followed through the system. To include plastic products in the case study could have improved the result and given a more inclusive case. Another factor impacting the result is the chosen distribution for the current 3DP scenario. It was decided to source the 3D-printed pipe from Europe, due to the information provided. If instead a supplier in North America would have been chosen, the environmental impact could have been reduced significantly already in the current scenario.

However, the results from the case study still confirm that 3DP can have great positive impact on the lead time. Although, at the expense of increased cost. The increase in cost must however be weighed against the decreased inventory carrying costs and customer loss of revenue. To which cost Volvo is willing to solve a BO with 3DP needs to be considered. This must be based on what Volvo wants to achieve with using 3DP for BOR. It is believed that in five to ten years specific BOs can be solved within the BO KPI target to a lower or the same cost, however if Volvo wants to improve the BO KPI target, it is most likely going to increase the costs. Volvo has today a service level that is deemed feasible, from both a service and cost perspective. If related to Rushton, Croucher and Baker's (2014) graph (see Figure 7) the higher the service level is the influence on the cost is increasing. If the cost criterion is disregarded it is believed that in the future 3DP can be used to increase the BO KPI target, but also the cost. However, it is also believed that the cost for increasing the target will be lower than it would be today. I.e. the graph will have a less steep inclination. This is due to the lower indirect cost needed when using 3DP.

Additionally, the lack of theory about BOR must be emphasized on since it influenced the outcome of the thesis. The assessment of Volvo's BOR process had to be based on the benchmark at UniCarriers. To learn about how more companies handle BOs could have contributed to a better understanding of BOR and to decrease the knowledge gap in the literature. However, due to the limited time frame of the thesis only UniCarriers' BOR was studied and a sufficient understanding of BOR is believed to have been captured.

During the data collection at Volvo the authors experienced enthusiasm from interviewees regarding the technology. However, it is important to emphasize on that 3DP is not a complete solution and cannot replace all other production steps. In the future scenario in the case study the total lead time in a best case is believed to become three to four days and the sourcing lead time one to two days. This means that the customers still have to wait for the product and thus dissatisfaction will still be experienced. As mentioned earlier in Chapter 5.1, according to Bergman and Klefsjö (2010) it is not possible to increase the satisfaction by a basic service, i.e. a service that the customer expects to receive from the beginning. Even if a significant lead time reduction for long term BOs can be achieved with 3DP, it is important to consider that in the future the customer expectations will probably increase.

The focus of this thesis is to see how 3DP can be used to improve BOR, i.e. the reactive process and not how BOs can be avoided with help of 3DP. However, the use of 3DP shall not be limited to be used for the reactive process when a breakdown has occurred. To secure uptime is of high importance and therefore effort shall for instance be put on preventive maintenance to avoid unplanned downtime. 3DP can be used for preventive maintenance in a sense that it can shorten the lead time. How 3DP can be used for this require further investigation. Additionally, the use of 3DP should not be limited to BOR. At Volvo other advantageous applications have been found and if including a wider scope in this thesis, the result would probably be different. The vision of printing at the dealers is based on the highest potential in BOR. However, if using 3DP for additional reasons, such as lower inventory etc. the point of production could be seen beneficial elsewhere, perhaps at RDCs or SDCs. For Volvo to further investigate other applications for 3DP within the organization and to take strategic decisions on a Volvo Group level are therefore important.

If Volvo in future uses suppliers to buy the 3DP service or print the parts themselves is not considered to impact the case result. There are as mentioned risks and opportunities connected to both scenarios which needs to be considered. However, if relying on suppliers it is important to ensure capacity. This since today, the main part of the sourcing time is waiting time, which raises the question regarding suppliers capacity. To use 3DP in the BOR process in a standardized way, a more accurately lead time would be preferred than can be given today.

How 3DP can be used and affect BOR in terms of certain measurements is addressed in this thesis. However, how the implementation of 3DP in the BOR process can affect other processes and parts of the organization is not covered. Introduction of new processes and techniques in a set environment usually impacts business in more ways than where it is implemented. For example, the use of 3DP might affect selection of suppliers and how 3D-printed parts are sold. Also, inventory management can be affected by 3DP and 3DP shall maybe be taken into consideration in the segmentation of articles in order to help balance cost and availability. 3DP can also affect the distribution structure and the typical spare part distribution network presented by Van Houtum and Kranenburg's (2015) might not look the same in the future. According to the same authors the main objective with a distribution network is to deliver products within a specific time frame, i.e. the distribution might need to be altered if a shorter lead time wants to be achieved. Therefore, it is important to have wide business perspective as well as be considerate when introducing 3DP into the BOR process. Especially when it comes to a technique that is not yet quite mature, the cost for too rapid implementation can result in significant cost in future states.

3DP should also be set in relation to development of other technologies. This is something that has not been addressed in the thesis. It is important to consider how other technologies will affect the use of 3DP in the future. During the literature review it was noticed that there is more written about working proactively to avoid BOs than about the reactive approach. For instance, with the use of big data and telematics unplanned breakdowns can be avoided. It can be questioned how the need for 3DP for BOR will look like if progress is being made in other technologies used in a proactive manner. If breakdowns can be predicted and prevented with use of other technologies, the reactive BO situation will not occur.

7. Conclusion & Recommendation

In this report the aim was to assess the possibility to use 3DP for BOR where it is beneficial in terms of cost, lead time and environmental impact. This has been fulfilled and described in this report.

Customer satisfaction is highly dependent on fast recovery when it comes to BOs at Volvo. There are several factors impacting the BOR, these can be both within the company as well as outside. The requirement for a quick solution is one of the main factors impacting the BOR and is therefore a circumstance that 3DP needs to considerate. Today, the BOR is deemed for the most part sufficient, where standardized ways of working exists. However, there are also improvement possibilities that should be considered in order to improve the BOR and utilize 3DP to highest extent. The standardized way is not always followed and additionally can solved BOs remain at DCs for days before reaching the customer. The distribution set up today is additionally not designed for 3DP, as well as the IT-system's capacity. However, the conclusion from the investigation is that BOR is an area with high potential for using 3DP. Even if today 3DP as a technology is not quite mature to apply in the backorder recovery process. Highest potential today can be seen where the BOs is long term, low volume and regarding high value parts. The result shows that today lead time can be shortened for long term BOs, but at the expense of increased cost. However, the application has been noticed to be very case dependent and therefore difficult to generalize. A major drawback today is the lack of quality assurance and for BOs in general, the main restrictions are due to the limitations in lead time and product printability. The difference in environmental impact is in the current situation deemed insignificant due to the distribution set up.

In five to ten years the development of 3DP is believed to have evolved in both plastic and metal printing. This will result in a larger area of application and more printable products. It is additionally believed that the production will be quality assured to a larger extent which will increase the application area. The quality assured production is also believed to have a larger geographical spread which enables regional printing, which will result in shorter transportations distances and decrease environmental impact. Lead time, which is a constraint today, is also believed to decrease. This is especially for the sourcing, where the bottleneck can be seen today. The cost per product is difficult to assess if it is going to be more or less expensive than the traditional manufacturing way, what can be said however is that the indirect costs for products can be significantly lower due to the shift from physical to virtual inventory.

For the future, Volvo needs to make certain decisions regarding 3DP. One important decision is whether to make or buy the products. This is a strategically important decision and needs to be considered carefully since it will affect large parts of the company, not at least the distribution chain. Another decision is regarding which suppliers to cooperate with. To be able to fulfill the demand on fast BOR, short lead times and global presence is of high importance. Therefore, Volvo is recommended to continue map suppliers and decide which criterion is most important when deciding on partners. Volvo should also cooperate across different business functions and increase communication in order to utilize the potential of

3D-printing (Gartner, 2014) since there is already today ongoing initiatives but not always clear communication. Additionally, Volvo needs to decide on what 3DP aims to achieve regarding BOR and to which cost BOs should be solved.

The recommendation is also to increase knowledge within the company regarding 3DP and continue working with suppliers to monitor the development of the technology. Finally, it is suggested that Volvo performs a pilot test in order to get reliable results and a proof of concept for improvement of BOR with using 3DP and when the technology has matured, it is also recommended to introduce 3DP in the standardized work with BOs.

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Appendix I

Number of interviews and regarding what topic are presented below.

Interviews	Number of interviews
Backorder recovery	6
General Information	7
3D-Printing (Internal)	
Purchasing	5
Strategy	2
Technology	3
Previous Thesis	1
3D-Printing (external)	
Technology	2
Capacity (questionnaire)	2
Total	28

Appendix II

Questions sent to suppliers for information regarding 3DP.

- What is the capacity of the current 3DP process?
  - Lead time?
  - Cost?
  - Production volume?
  - Size, dimensions and materials?

- What service level is realistic?

- How do you think the technology development and capacity will look in 5-10 years?
  - Is a low volume, small series and small product the only scenario?
  - Is there anywhere you can see that 3D-printing can surpass the traditional way of manufacturing?
  - When do you think the technique is ready to be implemented in the automotive aftermarket?

- Where are you located?
  - Global or local precence?
  - Do you have expansion plans?
  - Do you aim for one big machine park or printers at several locations (regarding the parts service)?
  - Who are you targeting as main customers?
    - Organizations such as Volvo?
    - Which industries?
    - End-consumers?

- What are you expecting from a partner such as Volvo?
  - Requirement on CAD files, logistics solutions, distribution etc.?
  - Are you providing complete solutions (transportation, packaging etc. or mainly the 3D-printing service/product?).
  - Are you expecting a close collaboration or an independent relationship?
  - What time perspective do you require in order to be able to produce and deliver products?