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ABSTRACT

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Abstract

This master's thesis identifies the possible effects which additive manufacturing might have on the spare part business in the future. A literature review is made on the topics spare part management, the current state of additive manufacturing and a combination of these two themes on how additive manufacturing can affect spare part management. Based on the made literature review is a theoretical framework created which identifies the spare part management process, what external factors could affect the adaptation of additive manufacturing into the spare part process and how this manufacturing method might improve the spare part process. The management of spare parts is divided into four phases creation, fabrication, distribution and prediction and additive manufacturing is seen able to possibly improve these three latter ones. The empirical data is gathered from Finnish high-tech organizations and based on the received answers three different scenarios are provided to show diverse possible outcomes how additive manufacturing might affect spare part business. The research provides findings that the main benefits of additive manufacturing is seen in decreasing inventory sizes, ensuring more accurate and faster lead times and more possibilities in the materials design phase.

Key words	Additive manufacturing, spare part management, scenarios,
Further information	

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HOW ADDITIVE MANUFACTURING MIGHT CHANGE SPARE PART BUSINESS

Future scenarios for Finnish high-tech companies

Master´s Thesis
in International Business

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1 THE EVOLUTION OF MANUFACTURING

This chapter provides the introduction to the conducted research and it provides the background of the study. This is followed with the aim of the study and in the end of this chapter are the research question and three sub-questions presented. They are explained including explanations on choices behind the specific aim of the study.

1.1 Background of the study

The so-called digital revolution is taking it shape in an exponential speed and it is said to have a huge impact on the manufacturing of products and other services in the near future. It is agreed among academics and industry leaders that the known nature of manufacturing and all the phases in the manufacturing value chain will get reformed. (Hartmann et al. 2015.) It has also been descripted as an industrial revolution which can affect logistics, manufacturing geographies and firm strategies in a radical way (Sasson & Johnson 2016, 83). Governments are giving significant funding for this new type of technology worldwide (Bechtold 2015, 9) and even the former president of the United States has pointed out the critical role of Three-Dimensional Printing (3DP) in strengthening manufacturing (Rayna et al. 2015, 90). The evolution of this new manufacturing technology has been viewed mostly on already developed countries and their needs, but additive manufacturing has the potential also to boost the economic growth of developing countries and bring these future economies in to the global distribution loop of all kind of products varying from manufacturing equipment to farming tools. Where additive manufacturing can decrease costs and increase efficiency in some parts of the world, it can simultaneously assist in creating new economies and improve the quality of living in other parts of the Earth. (Ishengoma & Mtaho 2014, 31–33.)

While 3DP or also known as additive manufacturing (AM) keeps evolving and its performance improves, some industries have already taken this method in to use. In this research the term additive manufacturing is used because it was more commonly used in the studied academic publications. According to Gibson (2017, 11) additive manufacturing and 3D-Printing are commonly used as synonyms but there are some arguments to make a distinction between these two terms. He states that 3D-printing is the more familiar one of these two and that this produces ready to use products which do not need the best accuracy or surface. Additive manufacturing on the other hand is a more staged process where the product is more complex, and the manufacturing takes more time. Also, Casey (2009, 54) writes that 3D-printers are low cost and very simple to use and “office ready” devices. However, in this thesis the term additive manufacturing is used as in the first place even though most studied researches do not need to make a difference between the two terms AM and 3DP.

Direct manufacturing processes, where customization is a key ability, are used in industry sectors like aerospace, automotive, construction and healthcare and the increasing adaption of it goes together with its technology development. (Despeisse et al. 2017, 76.) AM as an emerging technology has been compared to downloadable music and e-books: It can serve niche markets, in advance fabricated components are not needed and small batches can be made for the same price as bigger production quantities (Berman 2012, 155). AM has shared features with other digital technologies; digital created information has not to be at the same place of the production of the product and traditional business models get challenged from the more digital ones, which gives also additive manufacturing the potential to disrupt the traditional way of manufacturing. Additive manufacturing could also have a huge impact besides the production aspect, also on the supply and distribution chains. (Bechtold 2015, 7.)

Wiatt (2016, 54) has predicted that this technology will create over two million new employments until the end of the year 2020 but in hand seven million jobs will be terminated inside the globally 15 largest economies in the becoming years. Additive manufacturing will also change the competitive dynamics of economics of scale towards economies of single product manufacturing at least for some products and especially for highly customized products (Petrick & Simpson 2013, 12). Earlier additive manufacturing has been used generally for producing prototypes but also the possibility to manufacture customized parts and spare parts on demand is seen as an complement attribute of this emerging technology (Holmström et al. 2016, 6). Another changing factor which Petrick and Simpson (2013, 14) see is that additive manufacturing will localize manufacturing radically.

While the manufacturing technologies are evolving to a whole new level also the demand of spare parts has raised and the potential of the aftermarkets of manufactured products and equipment has been admitted. Manufacturing companies have been forced to improve their after sales operations due of globalizations and intensified competition on the manufacturer markets. It is not anymore useful to focus on single transactions from the customers but to steer the selling to a more whole product life cycle direction. The after sales of spare parts ensure additional unique selling points for companies and their importance is increasing by identifying expansion opportunities, exploring new markets and ensuring more customer retention. (Dombrowski & Fochler 2017, 133.) Also, Turunen and Finne (2014, 603–604) raise the fact that manufacturers in a variety of industries have changed their business strategy to a more customer focused approach including innovative solutions and sales of additional product related services like spare parts.

It has been estimated that around ten per cent of original equipment manufacturers (OEMs) annual revenues consist of spare part sales but because of lack of spare part management they cannot reach all of the potential profits out of this sector (Cohen et al. 2016, 130). Kranenburg and van Houtum (2008, 946) have estimated that over 25 per cent of manufacturing companies' revenues originate from service businesses and they suggest to giving more attention to spare parts management because of these high numbers. The sector of spare parts has been before almost uncompetitive for OEMs but because competitors have seen the huge potential inside the spare part markets, primary product manufacturers are losing markets shares in this sector. Factors like the complexity of the spare parts, turnover rate and the high profits set the attractiveness of the markets for competitors and their efforts to these markets. The amount and need for spare parts are increasing because of all new revisions of products, which add spare parts to the equipment manufacturers spares portfolios and the varying legal and voluntary obligations to provide spare parts towards customers increase the amount of supplied spare parts. (Wagner et al. 2012, 78, 82.) The growing installed base and frail product demand have led value from manufacturing towards after sales where the margins are higher, and firms can acquire steady revenues after product sales for years in the future (Wise & Baumgartner 2000). Furthermore, because technologies evolve and make more demand for new kind of spare parts, intermittent demand of certain spare parts and the avoidance of enormous downtime costs on customers sites, equipment manufacturers have to have vast spare part inventories at hand (van Jaarsveld 2013, 5). It is also important to notice that spare parts have a stable demand and they can profit according to Knecht et. al (1993) to around 10 to 20 per cent of revenues for industrial companies. They raise the facts that spare parts are a profitable revenue stream which have high entry barriers, the selling company possess the needed know-how for selling the needed spare parts and when not cost-based but value-based priced spares have a relatively high margin. In most cases the company can be the only reseller of these critically needed spare parts.

In the year 2015 the whole AM industry grew 25.9 per cent to a 5.165 billion dollars business sector including all products and services related to additive manufacturing but excluding all research and development costs and revenues of additive manufactured products of OEMs and their suppliers. The average grow rate has been for almost two decades an impressive 26.6 per cent annually. (Wohler's report 2016.) Despite the common thought that additive manufacturing is more used in rapid prototyping and in households, most AM usage is on an industrial part manufacturing level (Oettmeiner & Hofmann 2016, 946). Deloitte consulting and Hewlett-Packard have stated that they will steam up their AM and digital manufacturing services and that "The fourth industrial revolution is upon us". The 12 trillion-dollar manufacturing market is ongoing a radical transformation and this kind of manufacturing will affect all companies and consumers around the world. (Venturebeat 2017.)

According to Faludi et al. (2015, 14) additive manufacturing is modernizing prototyping and even small-scale manufacturing. Compared to traditional manufacturing in additive manufacturing there are no specific tools needed which reduces production ramp-up time and cost. This makes it possible and economical to produce batches of only one product which means that customization and quick changes in designs are possible. (Mellor et al. 2014, 195.) Smaller energy consumption while manufacturing products, reduced raw material for end-products and manufacturing on demand are abilities, which are included in additive manufacturing technologies (Huang et al. 2013, 1192) and furthermore AM stands also out from emerging technologies to possess the potential to change the distribution of manufacturing (Ford & Despeisse 2016, 1574). Also, Ford and Despeisse (2016, 1574) bring up the environmental benefits of AM and raise up following benefits: Manufacturing generates less waste compared to traditional manufacturing, end products can be shaped to be lighter and so shrink energy consumption while in use, products do not have to be transported overseas anymore and because of the ability to manufacture on demand inventory waste and costs can be minimized.

Spare parts belong to companies after sale services and with these services it is possible to increase incomes in forms of more expensive prices due of added services like maintenance and ensured availability of critical spare parts. In addition, for higher prices superior after sale services can increase the first time and repeated after sales and ensure steady revenue even in the future. There are also changes in the field of spare part demand. Product lifecycles have decreased, assemblies have more subparts and the demand is more volatile than before. Furthermore, firms have customized their products and have extended the range of offering which in turn have increased the amount of needed spare parts. (Cohen et al. 1990, 55–57.) Also, the markets for spare parts are enormous and growing. Only in the United States of America the amount of sold spare parts and after services were around eight per cent of their annual gross domestic product (GDP) in 2015 making a worth of approximately one trillion United States dollars (Cohen et al. 2016, 129–130). Taking this into consideration and remarking that investments in manufacturing equipment and other greenfield projects are ricing (World investment report 2018, 7) is increasing the existing equipment basis and the need for spare parts and after sales. Because of this grow rate, the changes this technology might do to manufacturing and value creation chains, this research on additive manufacturing and its effects on spare part sales are important and especially topical.

So, it can be seen that there is a research gab what it comes to additive manufacturing and how it might change the spare parts markets in the high-tech industry. The spare parts markets are growing alongside the equipment base is getting bigger due of new investments (World investment report 2018, 7) and the also the expanding amount if various not similar components in the machines (Cohen et al. 1990, 55–57.). Uptimes of the production equipment are critical, but the variety of spare parts and long lead times are making the management of spare parts more difficult in the future if they are managed poorly (Behfard et al. 2015, 506–507). The potential, which additive manufacturing has in the production and supplying of spare parts in various ways (Oettmeier & Hofmann 2016, 949) and the size of the growing spare parts markets make it justified to research the topic of this thesis.

1.2 Aim of the study

In all academic researches and studies, it is essential to find the existing research gap that the proceeded research is aiming to fill. After this it is important to find out what has been found earlier on the topic, what are the concrete research questions and what are the ways of providing more trustworthy information to the researched theme. In the end of the research the implications and findings of the conducted study can be accordingly evaluated, and future guidelines of the topic can be generated for the becoming research.

The aim of this study is to analyse the current state of spare parts management and how additive manufacturing might affect spare part business. The focus is in the high-tech industry in Finland and this research provide possible scenarios based on the theoretical background and on an empirical research conducted to case companies. There has been conducted research before on how additive manufacturing might affect spare parts business in the aerospace industry and some suggestions have been made on how they might affect different industries (Holmström et al. 2010, 693–695; Holmström et al. 2004), but the aim of this study is to develop deeper understanding on how Finnish multinational enterprises think on this subject and what are the possible future scenarios for these companies. Like earlier presented, additive manufacturing is suggested to be the digitalization of manufacturing and there is a huge potential on how it might improve the spare parts business for manufacturing companies (Hartmann et al. 2015.) but because it has not yet breakthroughs until this day, understanding on the Finnish high-tech companies' opinions and thoughts are researched in this study.

It was earlier raised up that the aftermarkets of spare parts are not decreasing in the future (Cohen et al. 1990, 55–57) but this new technique of manufacturing spare parts brings many possibilities and possible threats to the production and distribution of spare parts. The supply chains consist of several parties nowadays and the networks between production and supplying are massive. Location of production, spare part inventories and IP-right of spare parts are examples on factors which may get revolutionized during the possible change from traditional manufacturing towards additive manufacturing in the future.

Like it was in the previous part presented, spare parts include waste of unused potential for enterprises (Wise & Baumgartner 2000) and the evolving technology of additive manufacturing might ensure that this specific field of after sales management could be even more profitable. According to some of the investigated academic publications, the improvement of after sales and especially spare part management has been included to restructure business strategies (Cohen et al. 2006, 259–260) but additive manufacturing has the potential to reform these services completely (Venturebeat 2017). For this reason, this thesis will focus on providing potential scenarios for managers responsible for spare part business and the research question is formed so that it covers this type of research.

This research is based on one main research question and three sub-research questions. All these sub-questions go align with the main research question and fulfil the main research question by dividing it into more functional sections. The research questions are following:

- How additive manufacturing might change the spare part business in the future?
  - What are the challenges in the spare parts management today?
  - What improvements can additive manufacturing provide to manufacturing?
  - What kind of scenarios can be seen for the combination of additive manufacturing and spare parts?

The main research question identifies the possibilities which additive manufacturing can have on the spare part management in the future. The question is formulated so that it provides answers on what might happen to the spare parts business because comprehensive results are not the focus of this conducted research. The sub questions give a good overlook on the existing situation in spare parts management and raises potential changes in the future of additive manufacturing can have towards manufacturing. The third research question provide future scenarios about the main research question and they will be presented in the end of this research. They will provide possible outcomes based on the found theoretical background combined with empirical findings. Also, the following presented theory is based on the research questions and provides a good theoretical background for the study and shows what the situation is at the moment on a general level around spare parts and additive manufacturing.

This research focuses on Finnish high-tech companies which have global trade of spare parts, and which have warehouses and sales on a multinational level. Because of the lack of time and resources other than Finnish companies where not included for the empirical research. Also, small and medium sized companies were left out of the research because organizations had to have enough resources to be able to invest in additive manufacturing technologies and they had to have also a wide assortment of spare parts. Another industry which could have been taken in to this research could have been the medical industry, but the adaption of the technology was slightly different compared to traditional high-tech firms supplying spare parts for their stakeholders. Other reason for choosing high-tech firms was that they might be already in a good starting point for the adaption of additive manufacturing because of standardized production methods and plans for manufacturing. In addition, the profits of the adaptation of additive manufacturing were assumed to be more significant inside the high-tech industry. It was not relevant in this phase if the companies had already invested in additive manufacturing or in what state they were if they had taught about it on some level. The theory about spare parts management is presented so that it does not make a difference between spare parts providers and customers, because the main theory of forecasting spare part demand and the logistics of spare parts follow the same patterns. In general, the spare parts sold today will not change on existing equipment but rather the production methods might evolve by implementing the additive manufacturing possibilities to the manufacturing strategies.

Additive manufacturing is not limited to the production for only spare parts, but the interest was to find out how the management of spare parts could be improved by using a new manufacturing technology. The reason for including future scenarios for the third research question was twofold: On one side the aim is to provide multiple possibilities of the plausible impacts with scenarios because there is no sufficient empirical data available to provide only one accurate answer for the research question. On the other side, additive manufacturing is seen as a technology which will affect whole business models and cause disruption in the manufacturing industry, so scenarios give freedom to explore all kinds of outcomes. Also, the angle to view the possibilities of additive manufacturing in the future is chosen because at this state the new technology has not been implemented to the chosen sector on a large mature scale. In addition, the possibility that additive manufacturing might be considered inside the manufacturing industry and especially for spare parts exist already.

This thesis will continue with the literature review of spare parts in general, additive manufacturing and a combination of these two theories. A theoretical framework is created based on the literature review and an environmental system analysis is made for the constructed scenarios. These will be followed with the research design, empirical findings and three possible scenarios which are based on presented theory and empirical findings on the research questions. In the end are the managerial implications, theoretical findings and research limitations are presented before the conclusions.

2 SPARE PARTS IN THE HIGH-TECH INDUSTRY

In this part the theoretical framework for spare parts management is set. The chapter is composed so that it presents how spare parts have been managed earlier, what have been the universal problems in it and it discuss the role of the aftermarkets of spare parts. In addition, spare parts on a universal level are analyzed and how their allocation, logistics and demand is organized globally. The key findings which come to different areas of spare part management are concluded to the figure 1 in the end of this chapter illustrating the whole spare part process.

2.1 Spare parts

Spare parts can be characterized as they are only needed after the primary products has been sold and their function is to preserve or re-establish the primary products' operability (Wagner et al. 2012, 81). So, the need for spare parts occurs when a part of the operating equipment or machine brakes and the defective part or component needs to be replaced (Kranenburg & Houtum 2008, 947; Wang & Syntetos 2011, 1194). The management of spare parts differ from the more common management of raw materials and finished goods. When it comes to spare parts there are at the same time critical components waiting in inventories and resulting stocking costs while at the same moment parts are needed somewhere else to prevent expensive shutdowns or to get equipment running again. (Duchessi et al. 1988, 9.)

Because equipment intensive organizations must have high system availability, defective machines are a challenge which raise the important availability of spare parts (Roda et al. 2014, 528). Another reason than equipment failure for changing spare parts are maintenance policies. Spare parts can be changed in situations where the part still works during maintenance as proactive and some spare parts are not changed until shutdowns if their breakage do not cause equipment breakdown. (Kennedy et al. 2002, 201–202.)

There are several issues like stochastic factors, the intensity of product usage, wear and tear patterns, rates of failure and maintenance policies which affect the demand for spare parts (Wagner et al. 2012, 70). Kennedy et al. (2002, 202) pointed out that part failures in machines are often dependent to something and it result problems if the dependence relation is unknown. They found out also that the demand of spares may be affected by cannibalism of other parts or units and parts can wear out on a pre-know basis. Although this preventive maintenance is scheduled, it can be seen still stochastic because of the actual demand size. This type of demand structure is usually intermittent meaning that the demand raises infrequently and in most of the check periods there is no demand at all. (Wang & Syntetos 2011, 1194.)

There is a variety of spare part providers. They can be supplied by primary product manufacturers, by bounded spare part dealers who have contrast with the original manufacturer or by wholly independent parts producers. (Wagner et al. 2012, 78–80.) Delivering a completely new replacement part from the original manufacturer is one option for resolving breakdowns of parts but for instance Behfard et al. (2015, 498) list couple other possibilities how to handle in situations where a part break. They suggest following options: To repair the failed part, to buy second-hand parts from open markets, to use applicable parts from phased-out machines, to substitute by a compatible part or to redesign the machine to work without the failed part. In this research the focus is in the reordering the needed spare part from the original manufacturer.

Spare parts are difficult to manage because high inventories are expensive to maintain, and they tie up enormous amounts of capital but in turn the unavailability of spare parts can lead to long and costly downtimes which directly affect the company's profit by shrinking production rates (Roda et al. 2014, 528). Wang and Syntetos (2011, 1196) identify two types of costs which can be related to maintenance policies: The costs which arise when maintenance is done and the costs which arise when maintenance is not done ending to a breakdown. Furthermore, the maintenance costs do not only consist on direct spare parts costs, but they include also direct labor and mechanical costs, electrical expenses and software maintenance and update costs (Öner et al. 2007). The spare parts inventory level depends heavily on how equipment is used and how often it is maintained resulting to the turnover rate of the stocked spares (Kennedy et al. 2002, 201–202). In the same way van der Heijden and Zijm (2016, 915–916) also mentioned similar reasons on what make managing spare parts difficult and add factors like a geographically wide spread install base, the larger variety of spare parts and many expensive slow-moving spare parts to the difficulties. Even if these factors make it hard to manage spare parts, Öner et al. (2007, 1856–1858) state that over 60 per cent of total lifecycle costs of capital goods may be related to the management of spare parts. On the other hand, customers have high expectations on long availability times of spare parts and the manufacturing companies are expected to fulfil these expectations (Wagner et al. 2012, 69–70) which in turn can lead to major cost reductions in this growing sector if management of spare parts evolve to a better level (Duchessi et al. 1988, 8).

Furthermore, the attitude towards spare parts is changing because organizations across industries have recognized that there is more than just the legal obligation to supply spare parts for their customers. It is possible to change declining revenues thru spare part sales and to increase profits on the primary product markets. One estimation is that 25 per cent of total sales come from after sales inside the machine and construction industry and two thirds of this revenue consist of spare parts selling and adding simultaneously up to 50 per cent to the total profits. Spare part supply beyond legal obligations is carried out to differentiate own offering among competitors resulting to a more loyal customer base and it can acquire even new customers which in turn establish steady revenues for a longer period. (Wagner et al. 2012, 69–70, 81.) Furthermore, Cohen et al. (2016, 130, 138) raise up that after-sales generate long-lasting revenue flows, which require only small investments, but they even point out that OEMs are losing shares of aftermarkets to third-party vendors after warranty periods of delivered equipment end. The quality of spare parts and ability to repair broken parts play an important role in the after sales markets. Therefore, quality is an important attribute which affects customers choice of the spare part supplier. (Pfohl & Ester 1999, 5.)

One point which make the management of spare parts difficult is that there might be hundreds or even thousands of components in a single system (van Jaarsveld 2013, 6). The basis of spare parts are the primary parts used in the original product, but later adjustments and modifications of spares in the equipment are possible but mostly difficult and costly to execute (Wagner et al. 2012, 80). Pfohl and Ester (1999, 5) raise the importance of the right labelling, numbering and documentation on spare parts for efficient and precise order consulting and order management. In addition, they state that careful documentation of the offered parts towards customers is important in providing good after services for customers also in the future.

Spare parts are normally categorized. According to Duchessi et al. (1988, 8), there are two principal criteria for categorizing spare parts: Individual spare parts stocking cost and part criticality. Because the critically levels of spare parts are different among parts the attention on the prediction on demand should be allocated according to each spare parts' unique level (Deduja 2014, 24). The critically of spare parts get various meanings based on the focus undertaken. On the maintenance perspective some spare parts are more vital but on the other hand some parts are more critical in a financial or logistical perspective (Roda et al. 2014, 531). Furthermore, the criticality can also be divided by two other factors: The possible consequences if the part fails and no spare part is available (process criticality) and to the control of situation (control criticality) relating to spare parts lead times, sourcing opportunities, type of materials, costs and predictability of failure (Roda et al. 2014, 531). Very often customers initiate changes and store critical spare parts proactively by themselves to ensure availability of these spares (Wagner et al. 2012, 78).

Furthermore Duchessi et al. (1988, 9) highlight that some spare parts are over managed taking resources away from the more critical ones. They state that the management of spare parts is not as organized as believed resulting to huge inventories of hardly ever used spare parts and simultaneously these inventories are lacking critically needed spare parts. Syntetos et al. (2009, 293) suggest that by categorizing those spare parts kept in stock, managers could facilitate their decision making, like stocking policies and forecasting methods, allocating more resources for the management of those critical parts kept in stock. Usually there are needed engineers, material managers, personnel who control quality and other experts to classify spare parts, but they may have different opinions on what attributes are important to evaluate (Duchessi et al. 1988, 9; Roda et al 2014, 533).

2.2 Spare parts and their supply chain management

Supply Chains are seen as an interlinked network between different companies, people and processes which are involved in supplying products and services to customers (Durach et al. 2015, 119). According to Perumal (2006) and the International Institute of Management, the core attributes which describe a flawless supply chain are providing high quality customer responses, the conversion of inputs into outputs in an effective way and increasing asset utilization. These attributes also have a central role in the suporiety of spare parts supply chains. An issue in the management of supply chains is to simultaneously reduce high inventory costs and still maintain a high service level towards the customer (Andersson & Marklund 2000, 483) meaning to increase inventory turnover and positioning spare parts locations better but the process is constrained by factors like available information, lead times of production and delivery, as well as manufacturing batch constraints (Holmström et al. 2010, 687). Andersson and Marklund (2000, 483) define the supply chain managements role in spare parts as they attempt to decrease operating costs while simultaneously ensuring that customers' satisfaction is on a sufficient level. Holmström et al. (2017, 687) state that the most difficulties problem is to provide a valuable service for the customer when simultaneously costs in delivery and production are decreased and most importantly stock outs of critical spare parts for the customers operations are avoided at the same time. If the companies' spare parts logistics are strategically aligned and efficient, they can act as a competitive advantage among competitors by lowering costs, increasing revenues and the firm can create better value towards customers (Wagner et al. 2012, 69). Deduja (2014, 28) raises up that supply chain data, like minimum order quantities (MOQ) and delivery times, are more essential for the receiving customer when they plan future supply of spare parts.

Different logistics strategies are used for different parts and spare parts logistics can provide competitive advantages for companies in times where revenues are decreasing in primary product business and manufacturers might get use of this potential advantage. This makes long term logistical strategies of spare parts even more important and knowledge and analysis of spare parts logistics become further essential. (Wagner et al. 2012, 71,78,84.) It has to be noted that also delivery times have effects on inventory levels: When the delivery time is long, and it might vary between orders, safety stocks are required to ensure part availability. Long delivery time also causes supply uncertainty and it raises inventory costs and the delivery time depends on the suppliers' inventory levels and the used distribution system. Also, the reliability of delivery influences customer inventory levels. (Pfohl 1999, 4.) Sometimes also warehouse policies might influence the delivery times. When complete deliveries are required, orders are not executed if some component of the shipment are not in stock when the shipping should already start (Andersson & Marklund 2000, 486).

In situations where sourcing options are limited, spare parts with low-demand rates can result that suppliers of the parts have dominant position in negotiations and these situations result often in long delivery times and high costs in procurement (Roda et al. 2014, 530). Duchessi et al. (1988, 10) state that the lead times for more expensive parts might be highly variable which makes the prediction of downtime costs and lead times hard. Long lead times can also be avoided with emergency orders. The lead times is shorter compared to regular deliveries, but they are in turn more expensive and these expenses should be calculated in to a cost efficiency function. (Kennedy et al. 2002, 212.) Emergency orders might also be executed so that the needed spare parts are borrowed or sourced from other warehouses or even from external suppliers (Kranenburg & Houtum 2008, 947). On the suppliers' aspect scarce resources should be managed so that priority customers are served first, and safety stocks withhold for them. If low-priority customers are served instantly with these resources, they get free rides and there is the possibility that priority customers might suffer from stockout situations. (Cohen et al. 2006, 266.)

Efficient supply chain management can result in minimal inventories of raw materials and input goods if there are managed so that they arrive just on time for production and by so inventory and warehousing cost will not be generated. This speeding up of inventory turnover can spare resources but there is always the risk of delayed deliveries which can result in problems in the manufacturing if right raw materials or input goods are not available at the needed time. (Hill 2007, 674.) In turn Holmström et al. (2016, 4) claim that there are many drawbacks if components are supplied continuously to assembly lines. Cost resulting from quality, handling and storing are multiplied due to the growing product variety and the manufacturers have to produce and offer the needed components for all these product variants. Ruffo et al. (2007, 23) add to these drawbacks factors like logistics, inventory and stockout costs and provides the better scheduling parts for manufacturing when required as an answer to reduce and avoid these costs.

2.3 Inventory of spare parts

Inventories of components and parts which are designated as spare part inventories are held to prevent long downtimes that would shrink companies' profitability (van Jaarsveld 2013, 4). The basic objective of spare part inventories is to ensure that the equipment is in an operating condition by the assistance of local maintenance staff. Because of this, the policies of spare part inventories differ from other inventory policies such as raw materials, unfinished products and final goods inventories. (Roda et al. 2014, 530.) Spare parts inventories can be seen as protectors against prolonged equipment downtimes. This specialized use pattern in turn result that spare parts stay in inventories with no function until they are needed.

Because there is no guarantee on how fast a broken part can be sourced from suppliers, companies must have a lot of critical spares in their inventories, which forces organizations to balance between expensive downtimes and costly holding costs of spare parts in inventories and even with the possibility that rarely used spare parts might become obsolete. (Kennedy et al. 2002, 208.) Cohen et al. (2006, 262) likewise argue that keeping low or even none inventory saves financial resources but on the other hand this result in long response times when parts have to be repaired or ordered reactively. Holmström (2004, 3) identifies too that ordering spare parts at demand requires too much time with conventional production technologies but on the contrary, there is the risk that stocked spare parts might never be sold to a customer. The matter of parts becoming obsolete occurs also when planning inventory sizes. It is hard to estimate on how many spare parts should be held in stock for obsolescent machines. (Roda et al. 2014, 531.) It may be difficult to replace parts when no one holds spare parts for obsolescent machines in stock and the amount of obsolescence differs between industries (Kennedy et al. 2002, 202, 208–209.) and common reasons for obsolescence are the evolution of technologies and falling demand (Duchessi et al. 1988, 13). The production of spare parts for obsolescent machines may stop years before the service obligation and due to profitability reasons, producers might ramp down the production of these spare parts and they have to decide how to cover potential future demand (Behfard et al. 2015, 498).

In general, inventories can be divided into safety stocks and cycle stocks which consist of regular demanded goods. (Duchessi et al. 1988, 10). Manufacturers should have safety stocks for critical items and use these stocks when needed. They have to refill and adjust these stocks carefully so that they do not have too much inventory but in turn they possess of the needed amount of spare parts to prevent shutdowns. (Deduja 2014, 28.) To avoid these production downtimes, there have to be safety stock policies for both planned and unplanned maintenances (Wang & Syntetos 2011, 1195). Duchesse et al. (1988, 8), state that all possible spare parts do not have to be in stock, which in turn would reduce the tied-up capital costs in each organizations inventory. They identify that it is important to have critical spares at hand so that costly downtimes can be avoided.

Also, a reason for avoiding too low inventories are stockout costs. Stockout costs can generate lost in sales and they occur if a part cannot be delivered when it is needed right from the stock. Mechanic work time is lost if there is a shortage of spare parts. This results in less production than the actual demand is and will in turn decrease the companies' income. During these losses in work time, value-added margins cannot be generated and the lost can be calculated to the stockout costs directly. (Jensen 1992, 15,20.) The costs generally include the mentioned lost in production and quality costs but there are also other types of costs and all of these costs are difficult to calculate (Kennedy et al. 2002, 202). For instance, there are indirect costs which cannot be allocated directly to stockout costs. These costs may influence managers and their administrative support staff on various levels because communicating new delivery times to the customer, changing production plans, backorder administration and extra customer contact. (Jensen 1992, 20, 22.) Global politics can affect inventories in a disruptive way if some materials or new regulations force companies to scrap stored spare parts because of new legislations (Syntetos et al. 2009, 301).

In some industries the investments in spare parts inventories can go up to tens of millions of euros and there is a huge potential in cost savings by improving the management of these inventories (Kranenburg & Houtum 2008, 954). Duchessi et al. (1988, 10) even pointed out that only a small percentage of items generate a high percentage of the total inventory costs. Problems usually arise when different deciders have different motives on stocking spare parts. Engineers in a firm might want to stock as much as possible needed spare parts so that their equipment keeps running all the time when in turn stock managers might want to reduce costs of inventories and by this cause long down times when machines brake and there is none spare part at hand. It is important to specify inside the firm what is the common goal and not to pursue towards unique goals inside the same firm. (van Jaarsveld 2013, 5.) Behfard et al. (2015, 506–507) point out that because low volume production is no more economical, manufacturers have to produce large scale quantities and invest in additional inventories for these low volume parts to fulfil uncertain demand from customers. Manufacturers face also a challenge in new generations of produced products and their spare parts. They are usually obligated to provide spare parts for old and new generations of products and this magnifies the whole number of spare parts in stock. (Khajavi et al. 2014, 51.)

Also, as another option is the performance based model, in which the client pays for the services in align to the equipment's performance, so the maintenance responsibility stays at the equipment's original provider (Cohen et al. 2016, 134). The reason for this is because customers have bought the system or equipment at first place and they are interested in the runtime of the system and not in item specific performance. For this reason, part inventories can also be more system focused compared to the traditional single-item inventory model. (Kranenburg & Houtum 2008, 946–947.) In some cases, like preventive or scheduled maintenance the demand of spare parts can be predicted, and the needed spare parts can be ordered just in time so that they do not even need to be stocked but there occur also unplanned repairs and breakdowns (Kennedy et al. 2002, 203).

Companies must decide where to stock the spare parts and by this they can make calculations on responding costs to breakdowns (Cohen et al. 2016, 137). Spare parts suppliers have to weigh the benefits of fast responses towards customers with close locations of inventories with large piles of parts which in hand increases inventory costs (Cohen et al. 2016, 133–134), limits the possibility of pooling effects and transportation expenses arise (van der Heijden & Zijm 2016, 917). Another option is to store rarely used spare parts in a central location and more regular used spare parts could be stored more decentralized closer to the point of usage (Wagner et al. 2012, 89). Decisions on localization strategies of spare parts are seldom a simple task. The choice between these two basic strategies should be made according to country specific, technological and product factors. Even elements like trade barriers and volatile exchange rates affect the decision. (Hill 2007, 665–666.) Spare parts suppliers should determine their intension of spare parts sales because different goals can be achieved by differed strategies. By centralizing spare parts inventories the company acquires more profits from spare parts because of avoided storage obsolesce costs. If the target is to create more loyal customers then local and faster supply, over stocking of spares and fast delivery times are better ways to meet this target. (Wagner et al. 2012, 86.)

According to Cohen et al. (2006, 262–263) centralizing spare parts is an effective way of decreasing inventory costs and referring to Holmström et al. (2010, 690) it increases inventory turnover and reduces the need of local safety stocks but in turn it increases response times. Also, a mixture between these strategies is possible to provide fast supply by stocking some spare parts near to the customers location and locate the rest of the spare parts in a central location (Zanovani et al. 2005, 1). An alternative option is presented by Cohen et al. (2016, 135) that spare parts can be stored even closer than local warehouses by stocking them right at the customers' premises. Wagner et al. (2012, 77) hypothesized that top performers use a centralized approach and only fast-moving products are available at decentralized stocks and subsidiaries.

2.4 Forecasting spare part demand

Managing spare parts differs from typical product management: Spare parts requirements demands an extensive amount of knowledge and familiarization with demand mechanisms which vary significantly with common products. In the context of spare parts, constructing applicable rules is challenging owing to the distinct nature of the underlying demand patterns (Syntetos et al. 2009, 311–312.) Also, Deduja et al. (2014, 23–24) raise the difficultness of demand planning for the sake of numerous parts and their modifications, component failures and variant climates which affect part durability in multiple ways. Another reason for the problematic forecasting of part failures are the very low failure rates of critical and expensive parts according to Zanovani et al. (2005, 5). In contrast, demand forecast for wear parts can be made more accurate compared to spare parts, which demand is affected stochastic factors and breakdown parts are considered as unscheduled failures (Wagner et al. 2012, 82).

New products and machines create also challenges due to there is no previous data or reliable information on part failures (Simao & Powell 2009, 156). Kennedy et al. (2002, 202) identify that continues equipment monitoring eases the prediction of needed replacements but they also note that by reason of the expensiveness of monitoring, monitoring of all equipment cannot executed. Roda et al. (2014, 520–521) agree with the problems of new equipment and challenge of controlling the large variety of spare but they also add sourcing related problems like variation of material quality and dependencies on suppliers in forecasting demand.

One other reason which makes the forecasting of spare part demand challenging is the not uncommon intermittent demand of parts. It does not follow demand patterns, having time periods with none existing demand and it is not necessarily just for a single quantity or a regular demand size. The patterns of intermittent demand are characterized as infrequent, irregular intervals and variable sizes. If demand is described as intermittent it is often referred to as sporadic, lumpy or erratic demand in the academic literature. (Syntetos et al. 2012, 2101,2103.) Willemain et al. (1994, 529–530) agree with this and include that nearly all of the commercial forecast software do not take intermittent demand into consideration and they assume that demand is constant and regular, even though intermittent demand is encountered frequently by inventory managers and production planers. Typically, items which demand is characterized as intermittent are spare parts (Strijbosch et al. 2000, 1184) although intermittent demand can characterize all of a companies' product offerings (Syntenos et al. 2012, 2101). One reason for intermittent demand can be seen in the maintenance policies where defected components are discovered during maintenance inspections and the estimations on product durability are not reliable because time of failure and other factors leading to component breakdown are not accurate (Wang & Syntetos 2011, 2101).

2.5 After sales markets for spare parts

When companies started to offer rather solutions than products, it resulted in an increase of after sale services like installation upgrades, more frequent maintenance checks, trainings and other supports and especially growing the selling numbers of spare parts. These aftermarkets are characterized as unpredictable and inconsistent as a result of sporadically and unexpected demand. (Cohen et al. 2016, 129, 131.) Spare part supply has increased its importance as a competition asset in after sales services and it can bring new customers and bind existing ones if customer requirements are met (Pfohl & Ester 1999, 1). Also, Zanovani et al. (2005, 1) raise the growing importance of spare parts management and state that high system availability and the quality of after sales services have become central election criteria when choosing among system suppliers. They also identify reasons for the increase of spare part sales: Over the years companies in industries like automobiles, white goods, industrial machinery, and information technology have sold so many units but in turn, they are business with high margins and they account for a wide share of company profits. Although after sales services are sometimes seen as a necessary evil for companies if they are not managed efficiently and these aftermarkets are lost after warranty periods to third parties because of price competition. (Cohen et al. 2016, 129–130.)

By going more downstream from manufacturing towards services, companies can offer more products from the service scope which can ensure profits even in the after sales phase of the installed base. These profits are tempting for the reason that they produce continuous streams of income, require smaller amounts of assets than product manufacturing and they have usually better margins. (Davies 2004, 731.) Wises' and Baumers' (2000, 3) opinions on after sales go hand in hand with the earlier presented benefits and they include that downstream markets are often countercyclical and so balancing revenue incomes over the years. In addition to these benefits, companies can acquire deep understanding on customers' processes, technologies and plans which give companies unique customer information what is a competitive advantage against competition (Cohen et al. 2016, 130.)

Even though, spare parts markets are competitive, and customers might choose a competitor as a spare part provider because of a better after sales service, the spare parts markets are enormous in the result of a large installed base of units. Customers reason to choose their spare parts supplier is mainly the price but they are also not willing to make long contracts whit the supplier which would tie them to a single supplier in to the long future. This in turn is the opposite for manufacturers who should establish long-term partnerships which lead to strong customer loyalty. (Wagner et al. 2012, 78–89.)

The role of after sales services will increasingly become more important for profitability and overall business when manufacturers within various industry settings keep competitively differentiate themselves (Close-Up Media Inc. 2014). Cohen et al. (2016, 130) in addition wrote that the number how high customers rate a company's after sales services usually tells how loyal they are towards to company. Digitalization is a factor which can change the aftermarkets and practically the sales of spare parts when the focus changes from quality and prices towards delivering value to the customer. Customer value is seen in this context as preserving the products in an operational state with high reliability by providing the needed parts and skills with a high fulfilment rate and still for low cost. (Khajavi et al. 2014, 50.) It is important to change the attitude from spare parts selling as a must towards to see it as a steady way of generating revenue. Sales should not be ensured by offering free after sale services and by so cutting of future cashflows of the sold product. (Wise & Baumer 2000.) Another way of meeting customer demand of failing units is to replace the whole unit with a spare unit, but this is at the same time to most costing way of spares for the supplier (Cohen et al. 2006, 263). Figure 1 illustrates the spare part process on a general level.

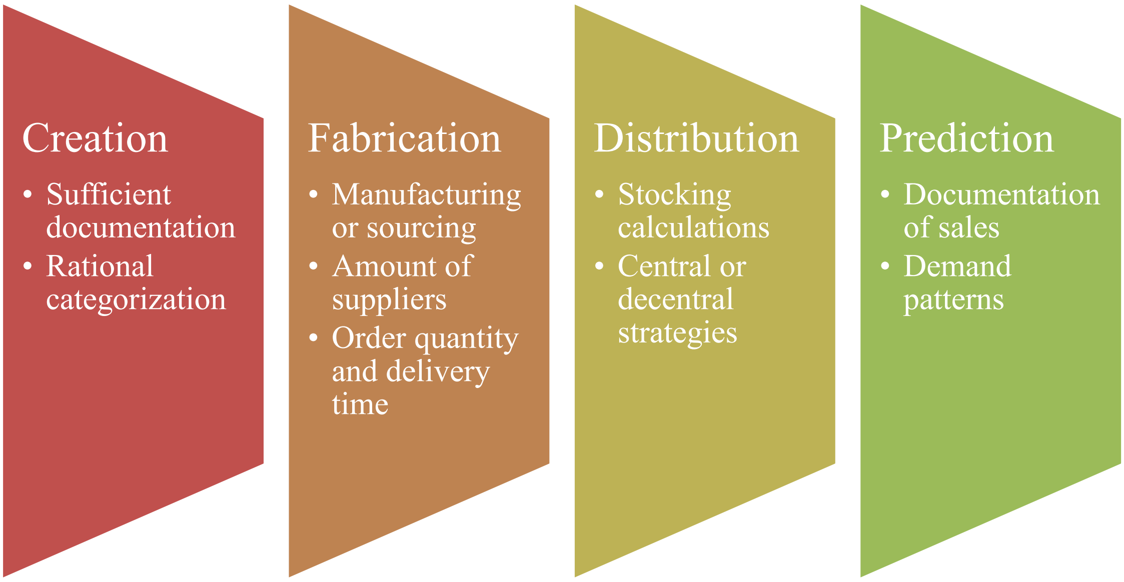

Figure 1 Spare part process

All of these four phases in figure 1 have been discussed earlier in this chapter and they all have to be managed carefully so that the managed of spare parts is efficient and more profitable. All starts at the creation phase in which sufficient documentation is needed to ensure that when actual demand for the specific spare part arises the spare part provider has the needed information to proceed in manufacturing accordingly. After this the spare part should be categorized to either one or multiple categories according to the sourcing category, demand patterns, criticality or other provided criteria. The second step includes the actual manufacturing of the part and it has to be decided is the needed spare part manufactured by the company itself or should external suppliers be used for the production. The company has also to decide on the number of the supplier they have for the material and ordering quantities of the part. If there are only few suppliers, they have more negotiation power on prices and delivery times but in turn if there are too many suppliers it might be hard to manage all of them and prices might get higher due of smaller ordering quantities from the same supplier. The quantity of ordered pieces and increase costly stock but in turn smaller batches can have higher unit prices.

Distribution strategies in turn should be considered if it is more important to have stock at hand and deliver spare parts with short delivery times for customer needs or if the focus is on having a more efficient inventory and decrease costs which arise from stocking. Each spare parts stock turnaround speed should be known to manage inventories in an efficient manner. Also, the location of the stocked spare part plays a role. Centralized stocks are more cost efficient but stock which are closer to the customer increase value for the them. Finally, the prediction on future demand is important to be more efficient in the steps fabrication and distribution. Available historical data on sales and demand patterns help in the forecasting of incoming demand which in turn can decrease stocks, stock-out possibilities and decrease delivery times.

This chapter identifies the current state of spare parts management according to investigated academic publications. Figure 1 sums up the key findings of the different phases in spare part business into one figure which in addition identifies key challenges in spare part management. The aim of this research is to show how additive manufacturing might change spare part business and the next chapter will provide general information about this modern manufacturing technology and in more detail, what are the main benefits of it compared to more traditional manufacturing methods.

3 ADDITIVE MANUFACTURING

This chapter will provide information on additive manufacturing based on academic publications. The technology itself is only discussed briefly because the aim is not in the technicalities but in how this technology can be adapted into industries, what are the benefits, challenges and the future of it. This chapter identifies different variations of additive manufacturing but when the term is used in this thesis it does not make a difference which variation is used and only AM is used as a general term of the technology.

3.1 Current state of additive manufacturing

Additive manufacturing technologies have existed since the 1990s and former they were known as rapid prototyping (RA), which was an accurate description at the beginning for this new technology. The first objects which were fabricated using additive manufacturing techniques were quickly manufactured prototypes out of digital computer aided design (CAD) Data. Nowadays the development has made it possible to manufacture even final products for industry usage and not just visual prototypes. One big step in the evolution of this technology was compared to the early stages of additive manufacturing the ability to manufacture products also out of metal, polymers, and ceramics and not only from plastic. (Atzeni & Salmi 2012, 1147.) Since the production equipment were huge investments, the technology spread on an industry level at first, but the situation changed by time and more affordable models were introduced for privet usage (Chen et al. 2015, 616–618). AM has reached the state that todays' published literature of additive manufacturing focuses mostly on how it can be adapted to spare parts and more complex parts (Holmström & Partanen 2014, 427–428).

A wide range of manufacturing technologies fall under additive manufacturing, but the principal idea is almost the same in each of them. The object is fabricated by stacking multiple 2D-layers one-by-one layer upon layer to form a 3D-object. After the first layer is fabricated, starts the fabricating of the second layer on top of the first layer and so on. (Oettmeier & Hofmann 2016, 945.) This manufacturing process will be illustrated in the figure 2 in this chapter. In machines where metal is used as the raw material, nearly all technologies of AM use energy beams or lasers to smelt metal powder from a powder bed selectively and precisely in to a 2D shape (Atzeni & Salmi 2012, 1149). After the layer is formed a new layer is added top of the previous layer and the whole process starts from beginning and continues until the last layer is fabricated (Gibson 2017, 11). The manufacturing machine uses the given 3D-model (CAD-data) to produce the needed layers for the manufactured object (Chen et al. 2015, 616). CAD-data consist of thousands of cross sections of each model and the installed CAD-software inside the device measures these given information precisely so that it fabricates a flawless object (Berman 2011, 155). To conclude, the basic idea of AM is to join materials to each other from a 3D-models' data, usually layer after layer and the result can be very complicated geometric object with groundbreaking material properties and advanced features (Rejeski et al. 2017, 22).

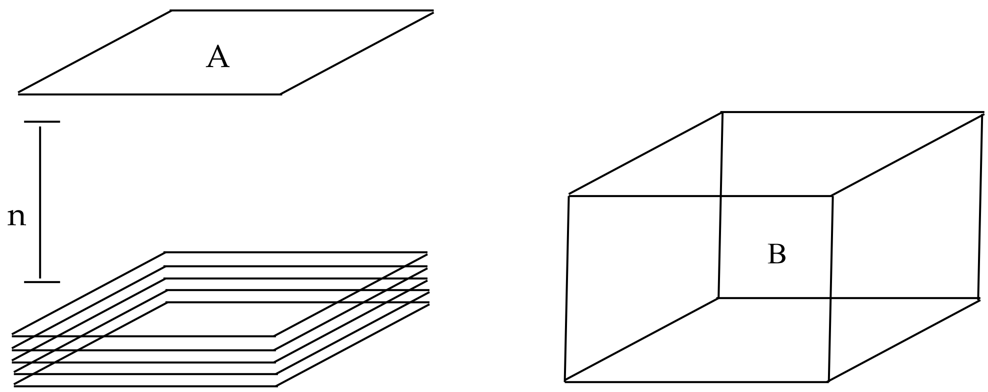

Figure 2 Basic principal of additive manufacturing

Figure 2 illustrates the basic concept on how additive manufacturing technologies work. The shape A in the picture can be seen as a basic 2D-cut of the material, which has its own dimensions. Printing starts by printing the first A shape and continues to print the following 2D-cut on it. After doing this process multiple times it will produce the 3D-object B in the picture. This is how additive manufacturing technologies work in general, adding 2D layers after layers on top of each other to form a three-dimensional object. Unlike in the given example shapes they do not have to be identical to each other allowing additive manufacturing to create hollow structures and to print any possible 3D-object.

Nowadays also the range of used materials contains steel alloys, aluminum, precious metals, plastics and as filament materials paper, wood, wax, clay, concrete, sugar and even chocolate can be used as a raw material. The materials status divides the processes into three different categories: Powder, Liquid and Solid based categories. (Chen et al. 2015, 616–618.) Gibson (2017, 1574) listed following production technologies which AM covers, and which are widely adopted in the industry:

- fused deposition modelling (FDM)
- stereolithography (SLA)
- selective laser melting (SLM)
- selective laser sintering (SLS)
- digital light processing (DLP)

When manufacturing is done with AM technologies there are no conventional fabrication limits compared to traditional manufacturing. All shapes and geometrical forms are possible to be manufactured with one machine and limitations due of molding or other traditional manufacturing restrictions do not longer exist. AM technology also does not have tooling costs between different parts and customization of each part is possible needing only model specific design data. (Atzeni & Salmi, 2012, 1149.)

Weller et al. (2015, 53–54) in turn raise four advantages which additive manufactured products have. First, they can be fabricated instantly from the existing 3D-model. Second, no tools are needed, and customization is free and flexible. Third, complexity of parts does not add additional costs to the production (excluding increased material, energy and time usage during the fabrication process) and finally, products can be manufactured so that they do not need further assembly operations because they can be manufactured as one functional and final piece if needed. Because of minimizing the part count, also time can be spared from the time and labor consuming assembly processes and it can as well be spared from tooling, which in turn could take even several weeks in some cases. These savings in time are most likely profitable in the long run for the manufacturer. (Atzeni & Salmi 2012, 1148.)

If there is no need for tooling and molds, AM has a very low fixed cost and it is more economically to produce small production runs compared to traditional manufacturing methods. This in turn makes it possible to enter niche markets and meet customers unique demands more profitably. (Berman 2011, 157.) Rejeski et al. (2017, 21) found also environmental benefits which AM provide: The material waste while production is enormously reduced and the supply chain is shorter. Additive manufacturing can be seen as a very flexible manufacturing technology which in hand is a competitive advantage on markets which are characterized as uncertainty, with high variety of products and countless consumer tastes. The flexibility in AM comes from attributes like low development costs, products are in short time on the market and AM has reduced capital intensity because it allows make to order fabrication. (Weller et al. 2015, 53–54.)

Additive manufacturing has characteristic's which are suited for make-to-order and for in advance paid orders. The production of individually needed pieces, none existing inventory of unfinished goods and lower personalization and customization costs can be seen as these features and which make additive manufacturing a more potential choice for the manufacturers. (Ford et al. 2016, 1579.) Additive manufacturing benefit in cost and time savings when the delays between designing and production can be decreased and products manufactured with AM technologies can result in savings while they are used (Gebler et al. 2014, 166). There are also other abilities which make AM a more potential technology in the future. Glassschroeder et al. (2015, 214) list three functions which can be integrated in additive manufacturing and which make it a more advanced technology. As one benefit they list that movable parts can be integrated to parts and objects during the manufacturing phase. Another improvement is that tempering channels can be integrated to the products allowing better thermodynamically features and finally as the third attribute they raise the possibility to add electrical functions to the parts because multiple materials can be fabricated to the same part. Furthermore, Ford and Despeisse (2016, 1575) raise the possibility to replace assemblies of multiple parts by producing the whole part as one ready assembly which in turn reduces or even eliminates assembly costs and because of the assembly provoked quality and time problems can be excluded. Gibson (2017) in turn found also the benefits of manufacturing a single structure but he in addition identifies the thermodynamically possibilities and brought up the ability to strengthen structures by including more resistant materials as supporting structures inside the objects. Items could also be produced closer to the end location and so decrease delivery times and parts could be upgraded more easily and faster because of the flexible nature of additive manufacturing (Ford et al. 2016, 1580; Holmström et al. 2010). Berman (2011, 156) sees also an advantage for AM fabrication methods compared to traditionally manufactured mass customized parts which come from various suppliers and require a high degree of supply chain management to assure that the suitable parts are at the right place and time when needed. If companies could manufacture these parts with AM by themselves, it would require less resources. (Berman 2011, 156.)

Until this day it is not possible to get energy reducing economies of scale by using additive manufacturing comparing it to traditional methods (Royal Academy of Engineering 2017, 11). Also, Olhager (2003, 326) points out that economies of scale are hard to be archived when not having an inventory of products. On the other hand, Ford and Despeisse (2016, 1575) states that AM technologies can be convenient economically compared to common technologies if they fabricate small or medium sized batches. Furthermore, they note that larger batches might be more competitive if AM technologies become more commonly used while the prices of the AM machines keep sinking. Most of the costs arise from part costs per machines and of the high material costs but it is logical to expect that when AM becomes more common also the prices of machines and raw material will decrease. (Atzeni & Salmi 2012, 1154.) It is expected that with this development rate of AM, unit costs will decrease because of significant improvements in the system productivities (Baumers et al. 2015, 200). Holmström (2004) argues that compared to traditional mass production, the primary cost of manufacturing does not consist of the length of the production, but it is generated due to the size of the produced part. Although studies have presented several potential effects of AM to manufacturing but there is an absence of explorative studies which measures the efficiency of AM in business strategies, different industries and environments, business models and processes and as a factor to gain competitive advantages for companies (Niki & Nonino 2017, 57). In addition, Piller et al. (2004, 440) list further costs of additive manufacturing including the greater complexities in planning of production and control as well as the need for a higher qualified labor in the production.

Durach (2017, 961–963) has found barriers which inhibit the full adaption of additive manufacturing techniques and when these mentioned barriers could be overcome. The found barriers were according to Durach:

- Limited variety of materials
- Difficulties regarding the development of new materials
- Insufficient quality of (metal) parts
- Stability and reliability of the AM process
- Education about AM–compatible design needed for AM engineers
- Low production speed
- Low accuracy and quality
- High material costs
- Regulations relating to materials (e.g. biocompatibility)
- Costs regarding the investigation of less-known AM material properties
- Consumer awareness and acceptance
- High manufacturing costs
- High equipment costs
- Limited long-term usability

Only one of these barriers (Consumer awareness and acceptance) was seen to be overcome during the next five years. Almost every other barrier was estimated to be resolved in the next five to ten years. These barriers were also rated on how they impediment to the dissemination of AM technologies and the most scoring barriers were related to problems relating to materials, quality issues and factors regarding production reliability, speed and education.

3.2 Additive manufacturing and sustainability

Additive manufacturing also provides environmental preserving abilities compared to conventional manufacturing. Beneficial attributes like producing less waste material, being more energy efficient and because products can be produced locally and transportation costs can be reduced makes AM a better choice for the environment. (Rejeski et al. 2017, 22.) Huang et al. (2015, 4) also raise up the possibilities to save in raw materials and energy consumption. They give an example on a titanium block from which 90 per cent is removed to produce the product and making 90 per cent waste, which cannot be reused without processing it before. To make the waste titanium usable again it must be smelted and formed to a new block again which drains huge amounts of energy. In contrast, 95 per cent of the unused raw materials in AM can be reused directly after local filtering and the system is designed so that it can reuse the unused raw materials in a closed-loop. Because less raw materials are needed, the need for shipping these materials is reduced and simultaneously harmful production of emissions is decreased (Despeisse et al, 2017 76–77.) When using AM as the manufacturing method, the needed energy for the production can also be chosen to be more sustainable. This is a step by which emissions can be reduced while the production and then the higher energy usage does not produce more pollution. (Krieger & Pearce 2013, 1514.)

One thing which also reduced emissions is that with AM it is possible to create parts with the same durability and resistance but with lower weight. Because of these new possibilities to create complex geometrical shapes and structures, the automotive and airplane industry can create more fuel efficient products and reduce emission outputs. (Petrovic et al. 2011, 1072–1073.) AM products have their entire life time better sustainability potential including cost, energy and CO2 reductions of five per cent in each category. The sustainability potentials which AM provides should be taken into account in industrial manufacturing in the future. (Gebler, et al. 2014, 166.) The common thought that AM is more sustainable has been proven right because it creates less waste and can create hollow structures into parts. Even though to achieve these economic benefits, the machines should be used on a daily basis. (Faludi et al. 2015, 76.) Even Reeves (2008) saw a decade earlier that additive manufacturing can decrease a company's environmental footprint by shortening transportation distances of produced products when they are manufactured closer to the point of use, which in turn can attract customers who weight these kinds of standards in their purchasing operations.

There is no doubt that AM produces less waste, but in turn the high energy consumption repeals the ecological benefits in the production (Faludi et al. 2015, 26). Because energy consumption can go align with carbon emissions, the energy usage has attracted the most attention in the AM environmental conversations. Compared to the conventional processes or machines, AM consumes much more energy per output unit. Many studies have been conducted on the energy usage of AM technologies, but they are usually made in laboratory environments and there is no standard test for the measures and the comparisons between result are difficult. (Rejeski et al. 2017, 25.) When discussing about the environmental performance of additive manufacturing, it is important to discuss the energy demand on the whole system perspective and not just process itself (Sreenivasan et al. 2010, 1575.)

Unfortunately, there has been made only little research on the impacts which AM technologies have on human health. The usage of harmful and toxic materials during the process and while disposing these waste materials, it can provoke dangerous impacts on employees' personal health. (Ford 2016, 1575.) Usually the environmental studies have been conducted to measure how much each process consume energy and how much waste is produced in the process, but the environmental aspect on how harmful the energy production processes are and how toxic the waste is in the manufacturing process are not taken into account in these studies (Faludi et al. 2015, 15). It should also be noted that AM can affect health issues on a different level by forming a more and more throwaway society, which has negative impacts on the environment by creating more waste and increasing energy consumption (Olson 2013, 36–37). It is hard and expensive to evaluate the environmental effects of AM because there are increasingly different variations in materials, feedstock forms, processes, locations and post-progressing options (Rejeski, 2017, 23). Another thing which makes it hard to measure the energy consumption is that the machines and their energy need varies a lot inside the same technology depending in the manufacturer of the machine (Rejeski 2017, 26).

3.3 Legal obligations and IP rights

Manufacturers have sometimes obligations to provide spare parts to already sold equipment to a certain point like until the warranty or service contract of the product ends (Wiatt 2016, 48–50) and the equipment manufacturers might tie themselves to deliver spare parts long after the actual production of the maintained equipment has already ended (Peres & Noyes 2006, 492). Additive manufacturing provides a solution of decreasing costs of inventorying these obligated spare parts by having them in a virtual inventory and parts are only manufactured on demand (Wiatt 2016, 48–50).

The evolution of this new manufacturing technology has raised new problems regarding intellectual property rights (IP-rights) of the produced spare parts. Holmstöm et al. (2010, 695) raise the risks of controlling property rights when the production of spare parts is located close to the point of use and the trust issue raise with the criticality level of the produced spare part. End users might use their own additive manufacturing machines to manufacture products based on illegal acquired blueprints from designers which are protected by IP-rights with no proper authorization and violate the exclusive rights of patent, copyright or trade dress holders (Depoorter 2014, 1485–1486). Patent laws are not the only way of protecting own additive manufacturing. There are trade secrets which plays a huge role in protection strategies, but it is costly to keep needed know-how in secret and trade secrets do not protect from reverse engineering. Reverse engineering is still hard to accomplish because printed objects do not reveal all the needed information for the reproduction. In addition to this additive manufacturing protection strategies include: Patent rights of AM components, processes and raw material manufacturing, trade secret protection of additive manufacturing processes, copyright protection of controlling software programs, design protection of AM object designs, and trademark protection for the additive manufacturing machine itself. (Bechtold 2015, 14.) Manufacturers can even control customers access to the produced parts because of intellectual property value. By restricting the access to the product, manufacturers protect the parts from developed scanning and replication technologies which make the potential coping process increasingly easy. (Holmström & Partanen 2014, 425–426.) If manufacturing is performed locally, also the needed production knowledge has to be distributed to the point of manufacturing. Compared to mass manufacturing where product designs are not shared, locally performed additive manufacturing makes product designs more open and it can hinder the adaptation of additive manufacturing as a secured manufacturing technology. (Holmström et al. 2016, 5.)

It is identified by Steenhuis and Pretorius (2017, 160–161) that AM has already affected IP protections and with scanning equipment it is possible to create the needed digital files for manufacturing copies of products which can affect spare part sales in different industries. The music industry has experienced a disruptive change because of digitalization and it is possible that manufacturing will also go thru this kind of disruption. The combination of developing 3D-scanning and reverse-engineering capabilities make part design sharing as easy as sharing normal digital files and there for the issue of property right of product design needs further consideration. (Weller et al. 2015, 46.)

Other problems are the so-called spare pirates and when suppliers sell spare parts direct to the end customer. Manufacturers have started to create market entry barriers to prevent these sales through the incompatibility of parts and special know how. (Wagner et al. 2012, 77.) Depoorter (2014, 1486,1495) claims that the legislation of IP-rights is not up to date regarding additive manufacturing and it is not likely to provide needed countermeasures to additive manufacturing copyright infringements. It is also predicted that the IP-protection might be a lost cause because even today illegal file sharing on the internet has not gained notable success of copyright enforcement against piracy.

3.4 Future development of additive manufacturing

Additive manufacturing technologies are rapidly evolving and they are starting or have already replaced more traditional manufacturing technologies in low-volume and high variety production (Holmström et al. 2016, 1). Even though, it was mentioned earlier that AM has advances in adding different functionalities to the manufactured parts, there is still an urge to develop the technology further. Unlike earlier presented, according to Ford and Despeisse (2016, 1578) microelectronics cannot yet be added to additive manufactured products and the technology needs more improvements in the technical performance so that the full benefits can be reached of this technology. One thing what is slowing down the evolution of this technology is the limited range of suitable materials for AM production (WDMA 2014) and especially stronger characterized materials are needed (Gibson 2017, 12). Jenkins (2015) gives one explanation for the slow development of the new materials; Leading corporations have not really tried to bring up new materials on the market for the additive manufacturing machines.

Campbell et al. (2012, 256) claim that attributes like speed, material properties, accuracy, nonlinearity and system costs are the major limitations for AM technologies at the moment. Berman (2012, 156) sees also the relatively slow manufacturing time compared to traditional moulding techniques as a disadvantage but for instead Hewlett Packard (2014) has been developing new printers which could be ten times faster and even more affordable than the existing models. Other abilities which need improvement are the maximum size of the produced parts and the accuracy in the whole process. In addition, one feature which needs more development are the so called “Digital Materials” meaning that the printers could print even hard and soft materials simultaneously in a single process or even determine optical properties like the color to vary during the print. The key for these features lies in the research of AM materials. (Gibson 2017, 12,14.) Another essential point which Niaki and Nonino (2017, 70) identify is the shortage of material suppliers in the AM industry which can offer enormous negotiation power for raw material producers.

Another key challenge in the additive manufacturing industry according to Despeisse et al. (2017, 81–82) are still the product defects. Weller et al. (2015, 45) have also explored the idea of lacking quality as an issue but they furthermore identify restrictions on available materials, production colors, precision and product surface texture complications. They also state that AM machines set limitations on a psychical level to product dimensions and there is no guarantee on how finished product will resist on different environmental impacts and high exposures of stresses. Another advantage which AM technologies provide is that components can be produced in situations where the shipping of the finished product might be very dangerous or expensive. These situations might occur in the military field where products are sometimes needed urgently, and the transportation is considered as a huge risk, but due to this technology these risky products can be manufactured at the point of usage if needed. International space stations might also get access to urgently required parts in a more economically way when parts could be manufactured in space and the need of expensive logistical operations for supplying these components would disappear. (Peres & Noyes 2006, 498–500.)

Rogers et al. (2016, 904) predict that additive manufacturing and its dynamic state will develop further in the becoming decade while the technology is still gaining acceptance among users. They foresee that this production method can change high-volume manufacturing and provide new opportunities and challenges for the future industries and their supply chains. Also, Gibson (2016, 17) sees the potential of AM technologies and state that the future for AM is bright having not yet explored opportunities left in the future. Additive manufacturing will be co-developed with other technologies and applications and some of them will reach maturity in the near future while some will evolve in something totally new and different.

Almost for a half of a century manufacturers have more and more been depending on a distributed and spread supply chain, sourcing the low-cost suppliers to manufacture components and parts of assemblies on a global level. The manufacturing methods and techniques employed by these manufacturers are based heavily on subtractive manufacturing methods, which begin with a solid physical form which has material removed from it (ground, cut, drilled, milled, and otherwise) to create the shapes needed to build components, parts of assemblies and ultimately complete end products. (Petrick & Simpson 2013, 13.) In the future industries must redesign their supply chains to be more align with the possible changes due of additive manufacturing in production. Many industries have already been forced to change their strategies due to new technologies and innovations like the retail, automotive and aerospace sectors. Already several studies have proven that AM has an effect on multiple actors inside the supply chain including suppliers, manufacturing companies and customers (Holmström et al. 2010, 695). While manufacturing of more complex products evolves and the need for instance assembly processes disappear, fewer stakeholders are needed and the directions of material flows change (Ford & Despeisse 2016, 1578). Additive manufacturing will also affect aftermarkets inside the spare part sector by decreasing lead times and inventory levels of spare parts and by changing their global logistics from shipping ready produced components towards shipping only product designs and plans to the AM machine (Wiatt 2016, 48). Also, Rogers et al. (2017, 950) wrote that AM make it possible for unparalleled possibilities of co-creation and customization of manufactured products which in hand lead to more agility and responsiveness towards customer needs.

Companies have to take new challenges like ensuring that sufficient work force, technological and financial resources are deployed to ensure the needed raw materials, meet new and variable customer demand, minimize potential disturbances and meet the required safety, commercial and quality standards in the future. (Rogers et al. 2016, 901.) Sasson and Johnson (2016, 90) identified that because additive manufacturing does not require huge setup cost, manufacturers who have invested in AM machines can also serve possible local demand of other manufacturers with the same machine they own. When production concentrates to individual manufacturers they can gain benefits of larger production quantities when ordering raw materials. These multiproduct producers can gain knowledge on needed spare parts production on a local demand level and also, they can produce customized products for the local need. Holmstrom (2004) agrees with this by writing that additive manufacturing is a versatile technology and the developments in different industries can improve each other. He opens that the same technician who is handling the specific AM machine could also produce parts for different industries and not just for his own field of expertise.

In a localized production strategy with AM the manufacturers who perform on demand production could also provide services from the product design to the manufacturing of the final product by getting the most out of this new manufacturing technology to serve also new customers outside the firms' traditional customer base. (Rayna & Striukova 2015, 94.) It is seen by Sasson and Johnson (2016, 91) that first the low volume production is most likely to be transferred to AM production, resulting that the finished stock inventories would change from products and components to raw materials for AM production. They rose up the thought that after the firm's own low demand production had been produced with AM technologies, they could also produce and serve other manufacturers' low volume production resulting that the firms providing AM production would need an even bigger inventory and stock for raw materials. More production result in more need of raw materials and this in turn can affect economies of scope for raw materials favouring even more the idea of the so-called regional supercentres of spare parts production. Holmström (2014) agrees with this that manufacturing between industries might get more feasible because the same AM machine and its operating specialist could produce the demanded parts across industries and support new ways of co-working among different industries.

There are many possibilities how additive manufacturing might change the manufacturing industry and one example from Berman (2012, 948–949) was that production of low batches could be transferred back to high wage countries because the need of staff while the production decreases. AM might also transfer the common way of producing large economical batches towards a mindset of produce on-demand and to fabricate the products closer to the point of consumption (Bogers et al. 2016, 80). Wiatt (2006, 53–54) brought up that in the near future a combination of the traditional and additive manufacturing is the most likely scenario according to many analysts believes. High volume manufacturing cannot achieve costs benefits with AM and it is seen to complement traditional manufacturing by providing more sophisticated solutions by combining complex shapes, reducing the lead times of new product and unifying tooling requirements. Additive manufacturing is seen to have to most potential to affect future manufacturing (Reeves 2008).

The found publications on additive manufacturing show that there are a lot of possibilities how AM could change the traditional manufacturing. It might be said, that there is still a research gap on the sustainability of AM, but the technology is still evolving in an accelerating manner and therefore also the ecological aspect will change in the future. This new manufacturing technology create also new challenges what comes to product quality, but it also provides new possibilities. The next part of the thesis will provide knowledge on how additive manufacturing and the management of spare parts might be affected.

4 ADDITIVE MANUFACTURING & SPARE SARTS

This chapter presents the relationship between additive manufacturing in combination with spare parts management. It compares the benefits of manufacturing spare parts with either on a scale or mass production basis, on a central or decentral production strategy and it will sched light to the possible effect AM has on the supply chains of spare parts. These theoretical suggestions aim to provide possible new ways for the management of spare parts with the help of the researched new evolving manufacturing technology and this last theoretical part can be seen as a combination of the two earlier presented theories on the management of spare parts and additive manufacturing. In the end of this chapter is a synthesis of the theory part and a theoretical framework.

4.1 Manufacturing spare parts with additive manufacturing

Khajavi et al. (2014, 50) emphasize that the digitalization of aftermarkets, particularly spare parts sales, can present both opportunities and threats for manufacturers for the reason that competition shifts from quality and price toward delivering value for the customer, meaning in general to keep products in operational condition with a good reliability. They argue that the major challenge to overcome has for long been to provide the needed spare parts with high fulfillment rates simultaneously at a low price, but additive manufacturing technologies can overcome this challenge. According to Sasson et al. (2016, 89) manufacturers will change their manufacturing of spare parts by investing to additive manufacturing techniques. These three-dimensional printing services are seen to encompass and combine manufacturing related services, which fulfill customers' part and product needs (Durach 2017, 965). Additive manufacturing technologies can configure spare parts supply chains by providing simultaneously more efficiently supply chain management and increase value towards customers (Khajavi et al. 2014, 50). Additive manufacturing will affect aftermarkets inside the spare part sector in multiple ways: It will decrease lead times and inventory levels of spare parts and it will change their global logistics from shipping ready produced components towards shipping only the product designs to the AM machines (Wiatt 2016, 48). Additive manufacturing will not only reduce inventories, but it will make it easier to confront intermittent demand and inaccurate market forecasts (Holmström 2004). Due to shorter inventories, also the inventory costs decrease, and the problems of obsolescence and product shortages can be overcome (Holmström & Partanen 2014, 423).

AM technologies can provide total cost saving due shorter delivery times, decreased downtimes and total costs for the customers and also better after-sales responses because more distributed production. However, there are still three major cost components which remain: AM machine depreciation, expensive materials and personnel costs. (Khajavi et al. 2014, 55–56.) Another perspective is presented by Sasson and Johnson (2016, 85) who raise the idea that additive manufacturing commoditizes production and even the rental of manufacturing units might be possible. Spare parts which are manufactured using additive manufacturing technologies can be used as temporary spares when a part in use breaks and the additive manufactured part is used temporarily until the original spare part arrives to replace this temporary part.

Customization is a beneficial attribute of AM technologies because it does not increase the manufacturing costs, and this can potentially be used by increasing prices for individually customized products and give a competitive advantage compared to none customized products (Weller et al. 2015, 48). Another possibility of AM can be seen in the repair of worn out parts. If components have long lead times and it is possible to repair the part with AM technologies, it can cut part costs and increase the parts usage period. (van der Heijden & Zijm 2016, 918.) On the other hand, Weller et al. (2015, 46) identify quality issues in manufactured parts as a problem of additive manufacturing and it is seen as a reason why some potential customers might avoid buying products which are manufactured with this manufacturing technology. On top of this also as limitations of additive manufacturing can be seen the printers chamber size, which sets a maximum size for the printed components, printing speed of the machine and the materials which are available at the moment (Durach 2017, 965).

4.2 Scale vs. mass production

In most situations the common production methods are more economical compared to additive manufacturing for mass production. Higher material and production capacity costs make additive manufacturing for the mass production not cost efficient and for this reason basic parts like nuts and bolts should be produced in large quantities. AM production is more feasible for parts with more complicated shape, because it does not increase the manufacturing costs like in traditional methods, but the size of the part affects the production in a negative way. It is suggested to take at least following variables in to consideration when choosing between make-to-order and mass production: used material, production method, distribution and inventory obsolescence costs and total life-cycle costs for the end user of the produced part. Costs like obsolescence costs can be eliminated if spares are manufactured just for order and no inventory is needed. (Holmström et al. 2010, 693–694.) Ford and Despeisse (2016, 1579) raise up the inventory costs savings if AM would be used. According to them by holding the needed production information at hand, products can be manufactured on demand and this minimizes inventory waste, reduces risk of none sold finished products and it can improve revenue flows if goods are paid before manufacturing.

Even tough parts which are manufactured with AM technologies can be more expensive than mass produced parts, it can be still worthwhile for manufacturers with a large variety of possible needed spare parts, when manufacturing orders are heterogenous and the existing aged install base requires low volume spare part production to ensure that plants can run more reliably. (Sasson & Johnson 2016, 89.) With AM it is possible to produce very complex components and whole assemblies in one manufacturing process and scale savings are minimal compared to common ways of manufacturing meaning that batch size is not a cost driver anymore (Holmström et al. 2010, 694; Hopkins & Dickens 2001, 201). Glasschoeder, et al. (2015, 214) brought up also the possibilities of additive manufacturing functional optimization and integration of products meaning the potential to manufacture whole assemblies of multiple sub-component with only one production run. Mass production and economies of scale will still co-exist in the future but the production of customized, low-volume and more complex parts will shift from traditional manufacturing to additive manufacturing (Petrick & Simpson 2013, 15). Additive manufacturing will change the production costs of high and low volume products. Low volume part production costs will fall while high volume parts' production costs will likely increase.

Holmström (2004) states that even though additive manufacturing cannot compete with traditional mass production in the manufacturing of high-volume parts, the situation of using additive manufacturing for low-demand parts is totally different already, because these parts have higher inventory and logistics costs and it is not economical to mass produce these kinds of parts. Another point which has to be taken into consideration is that when AM is competing with mass production, they cannot print the needed product and use the faster delivery time as an advantage if they do not possess of the needed digital drawings and files for the additive manufacturing of the part (Sasson & Johnson 2016, 92).

4.3 Supply chain management and spare parts production with additive manufacturing technologies

Additive manufacturing technologies can be used in situations where the supplying of spare parts is not possible. Reasons for this can be that the system is isolated geographically or temporally. By temporally isolated it is meant that spare parts are not anymore produced for the specific system, but AM can be seen as a solution for both these isolation problems. (Peres & Noyes 2006, 496.) Also, Holmström et al (2010, 689) identified that the benefits arise when producing spare parts with additive manufacturing for systems which are isolated, and the spare part demand is low.

There can be seen two options on how additive manufacturing might improve inventories. In the first option AM technology replaces inventory in a central location and in the second option, even the distribution of spare parts is replaced with distributed additive manufacturing, making existing local inventories unnecessary. Distributed additive manufacturing potentially decreases the need for large spare part inventory sizes and it gives the same kind of positive effects like inventory pooling, but inventories do not have to be pooled or parts stocked so massively. Additive manufacturing will change the concept of pooling from spare parts to pool additive manufacturing capacity among different industries. (Holmström et al. 2010, 689, 692, 695).

If manufacturers would not have to invest resources to physical inventories and their maintenance, they could focus their efforts more to the customers and provide them new value by offering more assured product availability or outputs (Holmström 2004). Usually the problems come from the so called slow-moving, rarely used spare parts which increase inventory costs by staying longer in inventories without demand. These costs are usually subsidized by the more profitable fast-moving parts whose demand is more frequent and they stay a lot less unused. (Holmström 2004.) If slow mowing spare parts could be eliminated from inventories, manufacturers could more efficiently compete with third parties in the offering of fast-mowing spare parts. Third parties usually provide only the more profitable fast-mowing spare parts and they do not have to struggle with the costs of slow-moving spares. (Holmström et al. 2010, 690–691.) Hasan and Rennie (2008, 584–585) support this also and suggest having frequently needed spare parts always at hand and produce infrequent parts only if demand occurs with additive manufacturing machines.

The transportation mode of shipping large containers will be replaced with smaller shipments which can be delivered with courier services and it might be that even the whole inventory management will get entirely transformed due to AM technologies (Petrick & Simpson 2013, 15). But in turn, Hölmström and Partanen (2014, 425) state that the fastest and most efficient way of replacing broken parts is to have an inventory of line replacement units at hand and merge digital manufacturing to chosen central support locations.

4.4 Central vs decentral

There is no more a need to centralize manufacturing because the need for centralized high-volume production is gone because low-cost sourcing of suppliers is not anymore, an economically profitable. This in turn will localize both sourcing and production and reduce economies of scale. (Petrick & Simpson 2013, 15.) Centralized additive manufacturing on demand to take over centralized warehousing is seen to be the first application of this new manufacturing technology because of the costs saving which can be gained by having less inventory to be managed. (Holmström 2004.)

By centralizing spare part inventories and production, the problems of delivery time and cost will remain. The solution has been to have inventories closer to the point of usage to respond quickly to the incoming demand, but it is still expensive and there is no guarantee that the needed parts are always available. One solution could be to replace physical distribution of spare parts with distributed AM capacity. (Holmström 2004.) Khajavi et al. (2014, 39) present factors like inventory and distribution costs and lower capital investments to be archived if the production is not in a single location. On the other side Wholers Association (2000) claims that a concentrated central production location is more economical because the AM machines can be operated simultaneously with one qualified person and when the production equipment is distributed to multiple locations, production capacity stays still the same but operating costs raise. Durach (2017, 957) identified that there exist barriers in changing from a centralized spare part production with AM machines to a distributed production strategy. He raises as barriers the capital and labor intensity and production cycle time in AM related spare part production. Sasson and Johnson (2016, 83) suggest that the on-demand production can inspire new business models which have centralized supercentres in which OEM and contract manufacturing is concluded by the manufacturer. Even this kind of business model focuses more on low volume, customized and high urgency production. As long as not all spare parts are suitable to be produced with AM technology, Holmstöm et al. (2010, 691) suggest using a combination of centralized spare part production with AM technologies and centralize also the warehousing of spare parts. The challenge in this combination is to decrease the inventory of these earlier mentioned slow-moving spare parts and simultaneously utilize the manufacturing capacity.

Khajavi et al. (2014, 58) list the following advantages which can potentially be gained by using additive manufacturing for distributed production: It can lower the overall operation costs, down times could be shorter, customers might more likely gain better customer satisfaction, higher flexibility, errors in supply chains could have a smaller affect, it would reduce expenses in inventory management and in logistics and potentially sustainability improvements if AM technologies and machines keep evolving further. A wholly new aspect of additive manufacturing and the location is presented by Holmström and Partanen (2014, 694). They present the possibility of mobile manufacturing where the production equipment can be transferred to the chosen location and the manufacturing location is not tied to one set place. They identify problems like varying atmospheres, difficulties in the calibration and reliable energy sources as the main challenges for mobile manufacturing. When time will pass also the size of these production machines will get smaller, prices will decrease and eventually they get more automated which makes it more feasible to distribute production to several locations changing radically spare parts supply chains (Khajavi et al. 2014, 56–57). Even Cambell et al. (2012, 256) predict that the prices of AM applications will decrease from the now experienced considerably high level when the usage of this production technology increases.

4.5 Macro environmental analysis of spare parts & additive manufacturing

A PESTEL analysis is used for scanning macro-environmental factors and it creates a framework out of these factors (Weisheng et al. 2013, 545). PESTEL is an analytical tool which identifies political, economic, social, technological, environmental and legal key factors (Vintila et al. 2017, 533). This PESTEL will analyze the external factors which can affect the adaption of additive manufacturing into the spare part business and each factor will be discussed separately.

Changes in politics can affect global supply chains. The instability in politics creates enormous threats to global supply chains, because tax laws, government policies and violence in the society can affect the overall circumstances in which the organization operates. (Ketterin University 2018.) The EEF study (BREXIT BRIEFING) shows that the changes in politics can change the organizations plans in future investments in manufacturing machines and equipment. The study focused on the causes, which the withdrawal of the United Kingdom from the European Union might have on manufacturing companies. These external political factors can change organizations strategies in supply chains and investment policies. Also, the notion from Syntetos et al. (2009, 301) that inventories are affected by global politics in a disruptive way if some materials or new regulations force companies to scrap stored spare parts because of new legislations can increase the willingness of companies to have smaller stocks of already produced products.

The evolution of scanning equipment which is able to copy existing spare parts and create needed production data (Steenhuis & Pretorius 2017, 160–161) is an external technical factor which can decrease the willingness of companies to invest to additive manufacturing. In addition other new technological development of the internet of thing, cloud computing, big data and cyber security can have positive effects on supply chain management (Ardito et al. 2018) which are similar to those listed in the chapter 4.3. Another new evolving technology is the industrial robotics. The demand for these robots has been increasing steadily and their core benefits are listed as reduced part cycle time, lower defect rate, higher quality and reliability and reduced waste. (Ghobakhloo 2018, 920–921.) These external factors might either compete with additive manufacturing or decrease the overall willingness to invest to additive manufacturing.

External economic factors can either increase or decrease the adaptation of AM by changing the demand for spare parts. It was mentioned that the spare parts markets are growing alongside the increasing equipment base due of new investments made on a global level (World investment report 2018, 7) and the also the increasing amount if different versions similar components in the machines expands the spare part assortment (Cohen et al. 1990, 55–57). Investment choices on a global level are affected by current economical state (Dhrymes & Kurz 1967, 428) and these investments positively affect the spare part demand. External economic factors affect the demand of spare parts in a long timeframe by changing the existing amount of equipment which need spare parts supply.

There are social factors which can affect the adaptation of additive manufacturing. Matos and Jacinto (2019, 88–89) identified that specific skills and education is needed among those people who work with additive manufacturing equipment creating a need for qualified employees. Furthermore they noted that new health and safety policies have to be reviewed for additive manufacturing. Chen et al. (2015, 624) identify that additive manufacturing might have social impacts on a micro and macroeconomic levels and lists job losses and work safety as factors which should be investigated more. Although they identify that additive manufacturing has a health benefit because more traditional manufacturing methods put employees under conditions of noise hazardous and oil mist. Tuck et al. (2007, 15) suggest that manufacturing could return to the local markets when migration of manufacturing to low-wage countries could be challenged due of AMs' low labor costs. The factors related to employment and work safety were identified as external factors which might affect the adaption of the integration of additive manufacturing into spare part business. In turn the wage costs are increasing in East-Asia (Obe 2018) which affect the manufacturing costs of spare parts and is also a notable external factor.

The awareness of the climate change phenomena might change attitude among individuals in organizations and affect their decisions toward a more climate friendly strategy (Halady & Rao 2010, 20). Also consumers are increasingly aware of the climate change and it has affected their consuming patterns. End consumers see their own possibilities to affect climate change as small but in turn they feel that it is the manufacturers responsibility to make a change. (Welles et al. 2011, 828–829.) Climate change can be identified as an external factor which can affect consumer attitudes and also motives on the spare part markets. Additive manufacturing can also result in a more throw away culture which affects the environment in a negative way (Olson 2013, 36–37).

Depoorter et al. (2014, 1485–1486, 1495) identified external competition who uses manufacturing data for creating IP-protected parts in their own production and in this way violate the exclusive rights of patent, copyright or trade dress holders. They also noted that legislation of IP-rights is not up to date regarding additive manufacturing and that provide an example that until to this date illegal filesharing on the internet exist and copyright are violated. In addition, Bechtold (2015, 20–21) identifies that while the key patents od additive manufacturing are expiring, is the open source community started to flourish and creating new innovative ways of using additive manufacturing, creating new production hardware and software but also patents are seen important in business strategies inside the additive manufacturing sector. It is therefore hard to say what the role of IP-rights and their protection is in the evolution of additive manufacturing. These all factors identified possible external events, which can affect the integration of additive manufacturing to the spare part business on some level and they can either affect it in a positive or negative way. These factors are used in the chapter 6.4 to provide possible background situations for the scenarios.

4.6 Theoretical framework on how additive manufacturing might affect spare part management

The theoretical approach of this research identified the current state of spare part management combined with additive manufacturing technology and what possibilities it might provide in the future. The literature review provided different approaches to both of these themes and presented in addition already existing combinations of these two theories. The main purpose of the literature review was to construct a theoretical framework for the empirical phase of the research and provide insight on spare part management, the current state of additive manufacturing and how it could change spare part business in the future. The figure 3 concludes the theoretical framework of this research and summarizes the findings of the literature review.

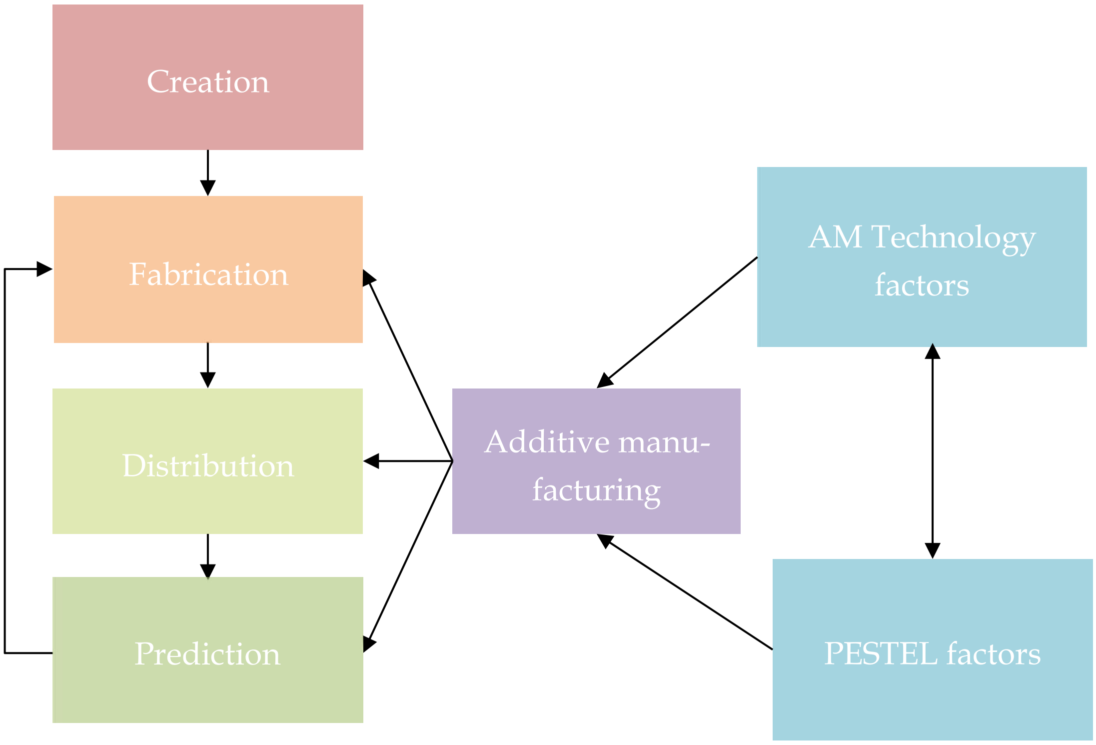

Figure 3 Theoretical framework

The figure 3 shows clearly that the literature review consisted of three parts. The left side of figure identifies the spare part management, the right side consist on external factors and in between is the combination of additive manufacturing and spare parts. The figure is in general the spare part process, how additive manufacturing might affect it and what factors affect the adaptation of this new manufacturing technology. Chapter 2 discussed spare part management and the Figure 1 explained the spare part process in more detail earlier and therefore those phases are discussed now only briefly. The basic idea is that all pictured four phases, creation, fabrication, distribution and prediction have to be managed efficiently to ensure profitable spare part business. All starts from the creation of the spare part, which must include enough item data and rational categorizing. This follows with the fabrication in which decisions have to be made on the choices between manufacturing or sourcing, the number of suppliers and ordering quantities and possible delivery times. The next phase distribution handles on inventory policies and storage locations, which need to be debated according to the organizations strategy. The final phase is the prediction of future demand. For efficient demand predictions it is important to have sufficient documentation on historical sales and be aware of the existing demand patterns. After the last phase, it starts the second phase over again creating a situation in which the organization has to rethink their earlier choices again if some of the phases has changed.

The right side of the figure 3 includes external factors which affect the adaption of additive manufacturing into spare part business. These factors are important for this new manufacturing technology to get it more widely used in the manufacturing of spare parts and if some of them changes, the other factors may be affected by it. They can affect the adaption of AM in both positive and negative way and they are external factors because individual organizations cannot change them by themselves. Furthermore, the changes in each of these external factors can affect each other in an increasing or decreasing way. AM technology as a factor itself has the biggest impact to the likelihood of adaption, although all the factors included in the PESTEL play an important role in the evolution and integration of additive manufacturing. The difference between the PESTEL analysis' technology factor and the presented AM technology factor is that the AM technical factor includes only AM related factors and the technology factor includes only other technologies.

Technology as a factor is the evolution of the additive manufacturing technology including the technology itself but in addition also the production materials for this technology. This factor was discussed in the chapters 3.1– 3.4 and the main message was that the technology itself has to develop to ensure faster adaption in manufacturing. There are still attributes like slow production speed, insufficient accuracy and high system costs (Campbell et al. 2012, 256), which need to be avoided to make additive manufacturing a better choice for spare part production. Even the possible production size is still affecting additive manufacturing in a negative way (Holmström 2004). In the past one of the biggest steps in the evolution of additive manufacturing was the introduction of new raw materials for AM (Atzeni & Salmi 2012, 1147.) but there are still materials which cannot be produced with AM. The lack of suitable materials slows down the evolution and it is partly affected by the demand factor. If there is no external demand for additive manufactured products there is low motivation to bring new materials to the market. (Jenkins 2015.) Furthermore the existing raw materials are expensive (Durach 2017, 961–963) which decreases the profitability of AM compared to more traditional manufacturing methods. Limited amount of raw material suppliers (Niaki & Nonino 2017, 70) and possible dangerous materials (Ford 2016, 1575) are not increasing the integration speed of AM. It is clear that the technological factor needs to be improved to ensure larger usage of additive manufacturing in the future. As long as this factor keeps developing the plausibility of more additive manufactured spare parts raise and the possible benefits of additive manufacturing can be acquired.

The PESTEL-factor consist of political, economic, social, technology, ecological and legal external factors which are discussed in the chapter 4.6. These factors provide findings about external threats and opportunities which can affect the adaptation of additive manufacturing to the spare part business. The chapter identified examples of each these external factors to provide a general picture on what could possibly affect the adaptation.

The main factor in the figure 3 is the additive manufacturing factor. This factor is based in the chapters 4.1–4.4 and it identifies how additive manufacturing might change spare part business. The external factors have a direct effect on this factor but this factor affects the three phases fabrication, distribution and prediction. The factor includes possibilities, which AM related possibilities might affect spare part business and make it more profitable. Chapters 4.1–4.3 included theory about how AM might affect the fabrication phase. It was presented that spare parts can be customized without any additional costs (Weller et al. 2015, 48) and the company can gain competitive advantages if they start manufacturing with AM and that batch sizes can vary according to actual needs without increasing costs (Holmström et al. 2010, 694; Hopkins & Dickens 2001, 201). In addition delivery times can be decreased and operation cost lowered (Khajavi et al. 2014, 58) which all have a positive effect into the fabrication phase. To conclude, AM can make the fabrication of spare parts more cost efficient by removing economies of scale and competitive advantages can be gained with shorter delivery times and stronger and lighter products.

Chapter 4.2 and 4.4 provide theory on how additive manufacturing could improve the phase of distributing. It was found that with AM inventory management could be easier because parts could be manufactured in demand and inventory sizes could be minimized (Ford & Despeisse 2016, 1579). AM production is already suitable for low-volume parts which possess high inventory and logistical costs (Holmström 2004) and additive manufacturing provides more options when choosing between central and decentral inventory strategies (Durach 2017, 957; Holmström & Partanen 2014, 694). With AM costly spare part inventories could be lowered and the management of stocks could be more efficient. The possible effects to the prediction phase are discussed in the chapters 4.1 and 4.2. Intermittent demand was raised as a problem in the prediction phase in the figure 1 and with additive manufacturing organizations would be able to confront this randomly occurring need for spare parts (Holmström 2004). Intermittent demand can be managed with costly safety stock but with AM it is possible to manufacture parts on demand if every documentation is ad hand which in turn decreases inventory costs (Ford & Despeisse 2016, 1579).

To summarize, the factor additive manufacturing can make the different phases of spare part management more efficient by confronting the problems which might arise in each of them in present spare part management. This factor is affected by external factors which in turn are linked to each other and the evolution of the AM technology is critical for the possible adaption of additive manufacturing to the spare part business. The figure 3 is the theoretical frame work of this research and it will help in the empirical and analytical part of this study. This chapter showed that there are many possibilities on how additive manufacturing can change the spare part business. All of the earlier presented findings from earlier published academic papers are later on analyzed compared to the gathered empirical findings. In addition to this figure 3 identifies the phases of the spare part process, to which additive manufacturing can have a positive effect and what external factors affect it. The following part will provide information on how the empirical findings were gathered for this theory, how it was analyzed and what was the overall trustworthy of this process.

5 RESEARCH DESIGN

This chapter consist on how the actual empirical research was done and how gained information was processed, and the overall study evaluated. It will include explanations on how the research approach was selected, why the specific interview styles were chosen and also a short review on the whole completed research. The part will end in a brief introduction on scenarios and why they were chosen for the following analytical part of this study.

5.1 Methods and methodology

Usually there can be identified two different approaches towards research: Qualitative or quantitative where the later one uses more numeric data and the first one tries to gain deeper understanding of researched themes and topics (Barnham 2015, 837) or the conducted research can be a combination of both qualitative and quantitative research methods (Mayer 2015, 55). This research is conducted as a qualitative research and it contains methods like semi structured interviews which are qualitative research methods of data collection. Neither of the methods, qualitative or quantitative, are better if compared to each other but they can be more suitable for a certain research problem (Eskola & Suonranta 1998, 14). A qualitative research approach was seen as the most suitable for this study.

Eriksson and Kovalainen (2008, 27) raise the importance of remembering that the chosen research problems and questions are the basis of the whole research and for this reason the research method should be chosen according to the research questions. Compared to quantitative research the research questions in a qualitative research are usually open ended (Cresswell 2009, 4) which is the case in this written thesis and this is one factor which suggests a qualitative research approach to be chosen for this research. Furthermore, also Hirsjärvi and Hurme (1991, 12) suggest that the chosen research method should be in align with the presented research question, but it is good to weight among all methods to choose the best fitting one for the research. A quantitative approach was considered in the early stages of the thesis but because of the lack of time and the intent to gain more understanding than absolute facts of the research topic the choice was made to conduct a qualitative research.

In qualitative research the idea is to interpret and understand the researched objective and provide better understanding of the issues (Eriksson & Kovalainen 2008, 5–6) which is the basis of this thesis. The main objective of this research is to find understanding on how additive manufacturing might change spare parts business it in the future. Investigatory research explores new insights into phenomena and the focus is not to seek for definite evidence but find empirical evidence for further research (Mayer 2015, 53). This was clearly the case when defining the research question and adding a future scenario aspect to it. It is clear that predicting future is never an absolute truth and this goes with Mayers earlier stated suggestion in line what comes to a qualitative research.

Qualitative research can be characterised according to Mayer (2015, 57) as flexible in nature; theory follows found data and the focus is to exercise techniques which seek to describe, decode and translate naturally occurring social phenomena. Like earlier said the open questions are common in qualitative research but they might even change during the conducted research. The flexible nature is a core attribute of this research approach. The researcher himself affects the research subjectively when facts and interpretation can be sometimes very hard to differentiate from each other. In this thesis the research questions have changed during the process and the flexible nature during interviews have made them more productive because complicated context has been spoken freely about and questions have been discussed in a deeper manner.

Brinkmann (2016, 521) argues that sometimes the qualitative research approach including interviews are chosen before a quantitative research because they are seen easier and as a more social way of collecting empirical data. In many cases, qualitative research needs more face to face interviews compared to quantitative research because the aim is to gain understanding of the research topic. Also, in this data collection process it could have been impossible to gain needed quantitative data from the interviewed enterprises because of limited resources and the used qualitative interviews gave all needed data for the research. Interviews as data collecting methods is the most popular way of gaining empirical findings in qualitative researches nowadays (Eriksson & Kovalainen 2008, 78). Because of the aim of the research was to gather information and reflect it to the found theoretical framework, interviews with specialists of additive manufacturing and spare parts were the most effective way of getting the needed empirical data.

An important thing in a qualitative research is to raise up the usefulness of the research and report the process and result clearly. One factor which makes it easier to understand the usefulness is to clearly describe the purpose of the study. The usefulness of this research is presented in the background of the study and the process and results are presented in the chapter 6 and 7. Another crucial thing to do is to show the findings in a simple but thoughtfully way and that the own interpretations are linked to the research questions. (Crescentini & Mainardi 2009, 437.)

5.2 Collecting data

In the beginning of the data collection phase for a research it should be defined what information is needed so that the research questions are answered in the end. It is important to be accurate on why the data is collected and from certain source and how it has been gathered. (Crescentini & Mainardi 2009, 434.) The data which was needed for this interview was chosen to be empirical findings and insights from managers and leaders who had opinions and thoughts about the research questions and because the aim was to gain findings on organizations from Finland it was natural to choose the source of data to be related to Finnish companies. When gathering empirical evidence of the theme, there are different kind of methods for the data collection (Kvale 2007). For instance, Marshall and Rossman (2006, 97) list several ways of how data can be collected in a qualitative research: The empirical data can be gained by participating by self in the phenomena, by observing the researched situation or event, by making all kinds of interviews about the theme or by gathering secondary information and afterwards analyzing these gained documents and materials.

In this thesis the data was collected by interviewing people who had professional knowledge about the researched theme. Interviews can be different according to their structure and on how active the interviewer is during the hold interview. In a qualitative research, a structured interview can be seen as the least suitable one out of interview styles, but semi-structured or open interviews are good structure types for a qualitative research. (Kvale 2007.) Also, Mojtahed et al. (2014, 87–88) identified, that there are many ways and approaches to arrange an interview, although usually they are characterized based on the dichotomy between structured and unstructured interviews but there are also other types of interviews like semi structured, group and focus group interviews. The main differences between these types of interviews are how the interview questions are formulated and also how the interviewed can respond to the questions and how many participants are included in the single interview setting. The conducted interviews in this research were a mixture between structured and in structured interviews to ensure to get differences in the data but still so that there was a structure which to follow during the interview. Different kinds of interviews can provide different information which in turn should be taken into consideration when choosing the interview style. A theme interview provides the opportunity to get more individual aspects in the answers but compared to an open interview there are still boundaries set with the themes. (Eskola & Suoranta 1998, 88.) This was also one of the aims in this research to get all kinds of answers and having an individual aspect inside of them. It could be noted that there were differences between the interviews when the number of participants rose. One to one interview took more time to get to the natural point, when in the group interview the participants could comment on other ideas.

In this research, the interviews were conducted as a mix between semi structured and open interviews having over 30 open ended questions which were presented almost in the same way in every interview (Appendix, Interview questions). Minor changes inside the order of questions, words and language made small differences among each interview but the message was the same in every one of them. Some of the questions were answered before the specific question was presented and if the information was seen as sufficient, the question was not asked during the interview. Kvale (2007) identifies that there are also problems in making semi structured interviews: It is not guaranteed that all the gained data is relevant for the research, there is in most cases a lot of data to be processed and sometimes even in semi structured interviews the topics might be to personal or forbitten topics during a recorded interview. The held interviews had a lot of good data and findings and all gained information was useable. Because the third sub-question focuses on building future scenarios about the topic, all the small details of the interview provide good aspects and findings for the future pictures and scenarios.

In qualitative research, interviews can provide a valuable way to find out how the real world is thinking about the research topic, but comprehensive and real understanding might occasionally be elusive. There are cases where the interviewer and interviewee speak the same language, but they can have different meaning for words and terms because of their backgrounds or a different worldview. Although these barriers can be avoided with good planning resulting in a good and rich set of qualitative data. (Qu & Dumay 2011, 239.) When preparing and contacting the target companies for the interviews the language, different meaning of words and backgrounds were considered as a challenge. Most of the experts had an engineering background and sometimes a more technical knowledge about additive manufacturing but the good preparation made the interviews not challenging and all used terms and words were familiar also for the interviewer.

In theme and open interviews, it is assumed that the interviewer has a wide basic knowledge about the topic which also results in more extensive answers (Hirsjärvi & Hurme 1991, 38). During all held interviews the basic knowledge was wide for every participant but the approaches where different: The interviewer had a more economic and business related approach compared to a more technical and experience based knowledge on the interviewed professionals. Although the interviews were semi-structured in this research, this point of wide basic knowledge about the theme gave more deeper understanding to the thoughts of the interviewees. In a semi structured interview, it is not necessary to ask the pre-formulated questions as they are written, and the order can also vary inside the interview. This makes it possible to get more insight about certain themes and it gives the interview a more natural flow. Also, if the theme is not followed or discussed on a daily basis or it contains themes which about it might be hard to start discussions, semi structured interviews provide a good approach to the them. (Hirsjärvi & Hurme 1991, 35–36.) Comparing these findings to the actual interviews, it helped the interviewed to speak more freely about the theme and in some moments, they answered for multiple prepared questions in one answer. It would have been distracting to repeat the same questions which had been discussed and answered already earlier during the interview. This goes in line with the findings that a semi structured interview resembles a human conversation in which a skilful interviewer can change the order of questions, style and pace to get the best response from the interviewee. Even more importantly, compared to formulas which have pre-decided answer options, semi structured interview enables to opportunity that the interviewee can provide answers in their own terms and language. (Qu & Dumay 2011, 246.) The endings of the interviews provided the most natural discussion because the asked questions provided more freely answers about plausible futures and not about actual situations.

Qualitative interviews can be hold like regular interview where the interviewer asks the questions and the interviewee answers these questions. However, the interview can also relate to a more familiar everyday conversation between the participants. By conducting semi structured interviews there is space to find out more about important topics from the interviewed and the interview resembles a more conventional conversation giving the possibility to speak freely about the theme. (Eriksson & Kovalainen 2008, 78, 82.) The interviews conducted for this research had qualities of both earlier mentioned interview styles, but it was remarkable that almost every interview changed at some point for some degree from a formal interview towards a more alike everyday conversation during the interview. Hirsjärvi and Hurme (1991, 25) agree that interviews can be seen as common conversations between two parties but as a difference between a conversation and interview and they raise the motivation and intention behind the interview. In an interview the interviewer has an intention to gather information and it is oriented to gain knowledge of the given topic. They also state that inside an interview there is the one party who tries to ask questions and lead the conversation and the other side talks about given topics and tries to provide answers to the asked questions. This was also the case in the interviews which were conducted for this research: The interviews had two participating sides and the interviewer had the role of asking the pre-prepared questions and lead the conversation and to get more out of the answers with more focusing and guiding questions.

Qu and Dumay (2011, 250) suggest that it is useful and important to provide the context and purpose of the interview in forehand to the interviewee and a debriefing afterwards. The basic concept of the interviews was provided during the first contacting and in the following contacting the persons were asked if they wanted to know more about the themes or the interview, but the basic themes were always enough for the contacted persons. It might have been not so profitable if all the prepared questions would have been sent to the interviewed person before the actual interview because they would have had time to prepare the answers too much and those could have been not so freely and intuitive in nature. Also, debriefing was done afterwards. The gained answers from every interview were sent to each person and feedback on the interpretations and possible additions were asked before finishing the analytical part of the study. This followed with sending the final version to the interviewed persons which provided them closure on the whole process.

There are different types of interview questions. In the beginning of the interview the so-called introduction questions are asked to prepare the interviewee and to gain their focus. Good introduction questions are easy and familiar to the interviewee but not related to the research questions. They are there to create a good atmosphere for the core questions. (Qu & Dymay 2011, 250.) They also raise the importance to ask the interviewee if he/she has any questions regarding the interview before the actual interview starts. All the interviews started with a small talk before the recording and when the recording started it followed with simple questions on basic information and educational and work experience were asked. During this phase the interviewed person was also asked if they had any questions regarding the beginning interview. These actions started the interviews and ensured a light opening for each conversation.

The basic questions are followed with the main questions which have been prepared before the interview to which the interviewer attempts to get answers during the interview. Between the main questions there is the possibility to ask follow-up questions. These are intended to extend the interviewees answers by rephrasing questions or by trough non-verbal sounds, nods or other body language. Then there are questions which can be asked before the next main question. They are called specifying and direct questions which are commonly asked to get more precise descriptions from general statements (Qu & Dumay 2011, 250.) The interview questions were separated into three groups and there were no time restrictions between the groups. Questions were asked mainly in the pre-chosen order but in some cases the interviewed person went individually to the next question, so they were then skipped if they provided enough information about the topic. Also, during an interview, the interviewer can ask specific and more focused questions and make sure that the other side has got the questions as meant and gather more information on themes which arise during the interview (Tuomi & Sarajärvi 2009, 73). Kovalainen and Eriksson (2008, 82) also noted that semi structured interviews there is the allowance to ask clarifying questions on the topic, asked questions and given answers. Couple times in each interview the question was answered very compactly so additional and more specifying questions were asked but, in a way, that it mainly helped the interviewed person to generate a wider opinion about the topic. In some cases, the interview question was answered forehand during some other question and if the data was not sufficient additional questions were asked on the specific interview question. The interview questions are divided into three sections in the Table 1 and it also present the formulated interview questions.

Table 1 Operationalization table

Research problem / research question	Sub-research Questions	Theory / Academic literature	Interview question
How additive manufacturing might change the spare part business in the future?	What are the challenges in the spare part management today?	Spare parts management	1, 2, 6, 9
		Aftermarkets of spare parts	3, 7, 10, 11, 12
		Spare parts as a product	4, 5, 8
	What improvements can additive manufacturing provide to manufacturing?	Additive manufacturing & spare parts	13, 14,
		Difficulties in adapting additive manufacturing	15, 16, 17
		IP-right & additive manufacturing	18, 19
		Additive manufacturing and supply chain management	20, 21, 22
		The disruptive effect of AM technologies on traditional manufacturing	23, 24
	What kind of scenarios can be seen for the combination of additive manufacturing and spare parts	Additive manufacturing as the only option for manufacturing Additive manufacturing covers slow-mover parts Production is localized but warehousing is still decentralized Production capacity is localized warehouses exist for bulk parts Spare parts business will be handled outside the firm in the future	24, 25, 26, 27, 28, 29, 30, 31, 32, 33

The table 1 identifies how the research question, sub questions, found literature and the interview themes and questions are related to each other. These interview questions in the table are preliminary and they worked as a good structure during the held interviews. The two first sub-questions about spare parts management and additive manufacturing are based on the found literature and the third one is a more future orientated question which is based partly on found academic publications and on interpretations on the whole studied literature about the future of the combination of spare parts and additive manufacturing. The interview questions were formulated so that they would provide empirical findings answering to problems which were found in the literature review and to the theoretical framework. Also, Opinions and expectations about the development of the research topic in the near future were wanted to be gained during the interviews.

The interviewed companies where all located in Finland and all of them had trade around the whole world. All of these companies can be characterized as multinational corporations with over thousand employees, operating in the high-tech sector and they all have services which include management of spare parts. All interviews were held face to face in the companies headquarter but some of the interviews were suggested to be hold via Skype, but this was not a suitable option for the target companies. The companies were selected with the given criteria, but the interview requests were sent on a general level to the organization. The companies were contacted via emails and the general message contained the research question, the topics which would be discussed during the interview on a general level and a brief reason why this research is conducted. All in all, 12 companies were contacted for the interview and five replied to the interview request. One of them replied that their policy hinders them to give an interview about the researched theme and one replied that they had not time or relevant knowledge for the study.

The interviewed companies are equipment manufacturers who have them self-manufactured install base around the world and their products range from machines to larger production facilities. These organizations where suitable for the research because they have a wide range of manufactured equipment and a large assortment of spare parts for these products. The companies' offered products are sold almost always in the B2B-markets, all of them contain tear and wear parts and the equipment are usually longtime investments which need frequent maintenance. These sold equipment are not in mass production and there are a wide range of existing product revision, models and unique designed products, which result in a large variety of needed spare parts. Because of the sensitiveness of the topic, the industries in which the companies operate are not opened fully but in general the spare part management of all these companies have the same functions, challenges and patterns. The interviews were conducted between April and November 2018 in Southern Finland. Also, company names and exact locations are not included in this research because of the sensitive nature of the topic. The basic information of the interviews and interviewees are presented in Table 2.

Table 2 Basic interview information

Organization	Title	Interview	Duration	Date
Company A	Director, Special projects	Face to Face	60 minutes	18.04.2018
Company B	Director Maintenance Field Support	Face to Face	75 minutes	26.06.2018
Company B	Director Supply Chain Operations	Face to Face	75 minutes	26.06.2018
Company C	Commercial product Manager	Face to Face	40 minutes	15.11.2018

The companies were contacted and asked for persons who have knowledge about their spare part services and at least some thoughts about additive manufacturing. The information about the upcoming interview questions were provided about the theme groups in the Table 1 to ensure that the companies had some assistance for finding suitable persons for the interviews. All of the interviewed persons were suitable because they knew about their organizations spare part business and they had at least basic knowledge about additive manufacturing and its capabilities. The position inside the organization was not requested to be at certain level but it can be seen in the table 2 that everyone was in a leading position in their business area. There is a variety in the specific fields in which they operate among spare parts and this gave more heterogenous approaches to the interview questions. Different opinions and aspects about the research theme provided unique answers and it resulted in more understanding how additive manufacturing could affect different parts of spare part business.

5.3 Data analysis

It is important to start the data analysis phase as soon as possible after the hold interview or even during the interview. The dialogue is still in the interviewers' mind and if additional questions have to be made it is easier to make them right after the interview and not couple weeks afterwards. Sometimes it takes time to get a good understanding and interpretation about the appeared problems. (Hirsjärvi & Hurme 1991, 108.) The data processing of data was started immediately after the interviews and by transcripting the interviews to a written format, which granted a good premise for the analyzing process.

When choosing among models which are used to analysing the gathered empirical content of the research there are plentiful options to decide from. These methods help to organize the collected data which in turn makes the analytical phase clearer when monitoring the empirical findings. (Eskola & Suoranta 1998, 159–160.) Thematic analysis was chosen to organize all the data gained from the interviews. Characteristics of a thematic analysis are a deep understanding and link between presented theory and empirically made findings, themes can arise from both empirical data and from theory and the intent of conducted thematic interviews is to discover new ways of spectating and relevant aspects of the earlier known concepts. (Eskola & Suoranta 1998, 174–175.) Because the empirical data was gathered with interviews which were semi structured the topics were discussed in an order so that the analysing process was not so time consuming. The gained materials of these interviews are organized and linked to the asked questions and for these reasons they can be processed more easily compared to open or narrative interviews. (Kovalainen & Eriksson 2008, 82.) Each question belonged to a specific theme and answers which did not fit into these specific themes, were analysed and reallocated to their own part. All the held interviews were recorded with an audio device and afterwards transcripted to a written form. After the transcription process all the findings were color coded to each specific theme, reorganized inside the themes to logical groups based on the question they answer and then analysed and compared to earlier found theory inside the literature review (Appendix, Coding structure).

Models can be found for the analyzation of the interview material, but thematic interview can be seen as suitable choice for structuring and analysing qualitative data. In this study the theoretical framework helped in the creation of the interview questions and because of that they also determined the relevance of all gathered data. The third sub-question uses all the material what was gained during the interviews and the organizing of this data was the hardest part of the data analysis.

The definition of a scenario is according to Glenn (2000, 2) a story which connects the present with the future by using plausible causes and effect links and presenting choices, situations and results throughout the narrative. These scenarios are possible and, in most cases, simplified explanations of how the future might evolve based on logical and coherent number of assumptions about key driving forces and relationships (Raju 2016, 589). Scenarios are exploration of alternative futures. It has been identified that there are multiple factors like technological development which impact change in the future, but the scientific knowledge is evidently insufficient to foresight and explore reliable alternative futures. So, because it is not possible to rely on the well-established scientific basis, we have to develop informed alternative futures based on empirical findings and structured conclusions: Future scenarios. (Fontela 2000, 12–13.) Even Bishop et al. (2007, 14) point out that the main driver for using scenarios is because of the uncertainty inherent in predictive forecasting. They identify that there is no situation where all information is at hand, human behaviour is hard to predict compared to physical phenomena and we even deal with systems in chaos in which the outcomes are almost impossible to forecast. Scenarios are used in this thesis because the aim is to provide possible scenarios of the future. The research question includes a still evolving technology and there are multiple possibilities how it might change the future and at the moment the gained information is usable to form plausible scenarios on the researched topic.

Scenarios can be told in two different ways: The first way are more qualitative scenarios which consist of descriptive and written narratives. The other way is for quantitative scenarios which are tables and figures using numerical data and in most cases these scenarios are generated with sophisticated computer models. To be exact the later presented way are projections and not scenarios but good scenarios include often forecasts and projections to provide backbones to the more qualitative scenario. (Glenn 2009, 2.) When writing a qualitative scenario, the researcher can act more creative when they enter the more complex field ever-evolving causal relations and interdependencies. (Fontela 2000, 12–13). This was conducted as a qualitative research and therefore also the forming of scenarios is done in a qualitative way. Because of limited resources and time there is no numerical data at hand and a quantitative approach for forecast nor projections was not possible.

Scenarios are usually attached to a specific time period which they describe, and they are not single predictions or forecasts, but rather multiple possibilities and statements organized about the investigated future. They are rather not just predictions or accurate forecast, they are possible explanations of what may happen and what could lead to that state from the present state. It could be said that scenarios try to explain how events and trends have evolved to their plausible state. (Glenn 2009, 2.) There are also arguments on why to form these scenarios. Bishop et al. (2007, 5) wrote that those can be seen as archetypical products of futures studies. They consist of following central principles: A vital role of them is to think deeply and creatively about the future so that possible risks are taken into consideration in advance and those risks do not occur surprised and unprepared. In addition, it is important to prepare for multiple plausible futures because the future is uncertain in nature and it cannot be trusted that an individual scenario will happen. When right formed, scenarios include different stories and these in turn can be used to decrease the possibility of totally unaware futures realizing. (Bishop 2007, 5–6.) If a scenario or any of the formulated scenarios do not happen, this does not mean that those scenarios were wrong or unnecessary because the possibility that they might come true is minimal and the aim is to be prepared or know about the plausible scenarios meaning that it does not even need to any actions be to taken in advance (Glenn 2009, 3) but scenarios can be also used to avoid unwanted futures to happen (Roxburgh 2010, 36) which in turn requires proactive actions from the individual or organization who is using the scenarios. The later on presented scenarios are set to a specific time and they show three unique plausible futures for the researched topic. They do not try to be factually correct predictions but to awaken ideas in readers and inspire them to think about the possible outcomes.

There are plenty of different approaches to create scenarios but in the end all of them steer to the same end result: identify plausible scenarios and with them evoke policies which are based on the presented scenarios. The used methods go from simple ones to more complex approaches and they can range from qualitative ones to quantitative methods. They can consist on similarities or have completely unique features and sometimes the terminology might change between methods. Almost all of the approaches identify the need to understand the system under study and recognise existing trends, affecting issues and happening events which are vital to the spectated system. (Glenn 2009, 5.) This research will formulate explorative scenarios. Explorative scenarios try to answer to the question: What can happen? These kinds of scenarios are commonly developed to illustrate plausible but different developments in a longer time horizon and they are based on profound changes. Two kinds of explorative scenarios can be identified: External and strategic. (Höjer et al. 2008, 1960.) The created scenarios in this research are the external scenarios because according to Höjer et al. (2008, 1960) they answer to a more specific question: What can happen to the development of external factors? The theoretical framework included external factors which affect the adaption of additive manufacturing inside the spare part business and therefore this type of scenario was chosen. These scenarios provide different scenarios which are affected by external factors, but they are plausible and not alike (Höjer et al. 2008, 1960).

A more simple approach was chosen for this research using both the theoretical and empirical findings and form three scenarios which differ from each other. Table 3 illustrates how the scenarios where created based on the findings. In addition, an environmental analysis was made to provide information on existing trends and states in the environment in which organizations offering spare parts operate. These results are discussed in the Chapter 6.4 and the PESTEL analysis in the chapter 4.5 analysis will be used to provide information about external factors which affect the adaptation of additive manufacturing to the spare part business to provide an environmental background for the scenarios.

Table 3 Formulating scenarios

	A	B	C
Fabrication			
Inventories			
Equipment location			
Legal obligation			
Competition			

Table 3 has the themes which were identified during the literature review and the hold interviews. All columns A, B and C are presented in more detail in the chapter 6.4 but this table 3 identifies generally how the analyzing of data was done with the assistance of scenarios. Each of these themes were important either because they were included in the theoretical framework (Figure 3) or because they were discussed more widely during the interviews. The columns A, B and C will include possible different outcomes to each theme and they are based on the literature review or empirical findings. The columns A, B and C do not present only a positive – neutral – negative range but in addition strategy choices, evolution and possible outcomes. After these cells are filled with the mentioned values, scenarios are created by picking one value from each row so that plausible scenarios are formed. By plausible it is meant that the individual scenario cannot be at variance with itself.

5.4 Trustworthiness of the study

When the research limitations are discussed comprehensively, it gives the research better understanding and trustworthiness (Crescentini & Mainardi 2009, 437). It is important to realize that interview situations are not random people who have happened to get together and to talk about a uniting topic. There has been a lot of actions resulting of these people to meet for this specific interview and share their knowledge on the specific topic. (Brinkmann 2016, 530–531.) The interviewed experts have had to take time from their own schedule to discuss the specific topic. Most likely if there would have been people who had negative feelings about the proposed theme and if they did not believe in the new technology it might have been that they would not have given the whole interview. All the interviewed professionals had some presumptions toward the topic because they were familiar to it and this could have affected their answers based in the former attitudes. The interviewed organizations might have had an optimistic attitude toward the topic because they were willing to speak about it and they saw potential in it. It might be that the companies who did not responded to the interview request had more pessimistic approaches to the topic and they did not for that reason responded to the interview request. Birkman (2016, 521) argued about the motives in the choosing between quantitative and qualitative research and the qualitative was identified as an easier approach. This approach was chosen for this study because the aim was to gather deeper understanding of the topic and with the limited resources a qualitative approach provided all needed data for a trustworthy study.

When a research has followed an objective approach, it means that the researcher's own values and beliefs are isolated from the test subject. In most cases, this is not entirely possible, but the researcher should recognize his or her own preformulated assumptions and state them in the written report to improve the overall trustworthiness in the report. These assumptions may affect the whole research process and research design, which should be noted when evaluating the whole reliability of the conducted research. (Eskola & Suoranta 1998, 15–18.) During the research process while gathering academic publications for the theoretical framework there were some beliefs and pre-assumptions on the topic. Most of the publications had an optimistic approach to the possibilities of additive manufacturing and own optimistic assumptions about the state of the technology were present in the early state of the research. Although they changed constantly when reading more about the topic and it was surprising to find even negative findings from different aspects on the researched topic. These pre-assumptions and attitudes toward the topic existed but all the found material about the topic was investigated systematically and nothing was left out because it was not in line with the existing assumptions or values. It has to be mentioned that the topic of additive manufacturing and spare parts can be seen as a neutral topic while conduction this study. Own values and motives around the research did not play a remarkable part and it was conducted therefore in an objective manner. Own experiences among spare part management provided more understanding about the topic but they were not used to lead the research to any specific direction or end result at any stage of the research. If own former experiences have affected the research it might have provided a more pessimistic attitude towards spare parts management resulting in a more problem orientation in the question formulating process.

It is also worthwhile to evaluate the trustworthiness of the study by using pre-existing criteria and compare the research against them. Mäkelä (1990, 47–48) raises four criteria that can be evaluated when evaluating the trustworthiness of a qualitative research and they are following:

- The significance of research material and the societal or cultural placement of it
- The sufficiency of material,
- The coverage of the analysis
- The ability to evaluate the analysis and to repeatability of it

This research will be evaluated with these four listed criteria and they will be gone through individually in order to determine the overall trustworthiness of this research in this chapter.

First the significance of research material and the societal or cultural placement of it is analyzed. In this research the empirical findings were gathered with two types of interviews: The first and last interviews were hold on a one to one basis were only the interviewer and interviewee were present and the second interview was hold with two interviewees at the same time. These expert interviews were afterwards analyzed and presented in this research but the granted empirical findings would be more holistic and specific if more interviews were conducted. For the limited resources and certain company policies only three deeper interviews were hold and this might have given a too narrow data collection for the analysis. (Mäkelä 1990, 48–52.) It is furthermore stated by Mäkelä (1990, 48) that the way and situation of gathering empirical findings and the possible effect of the interviewer has to be specified and analyzed. Even though the interviews were held in both Finnish and English, the results were aligned in most discussed themes and the communication language in the interviews might have had only a small effect on the received answers and findings by making misinterpretations. It may have affected the result more that there were a small variety of educational backgrounds among the interviewees ranging from business schools to technical universities. This might have had an effect on the interviews in some degree: people with a business school background might thinking about of the possibilities of this new technology more optimistic compared to more technical knowledge possessing persons, which has to be noted in the trustworthiness of this study. Although the interpretations were checked by the interviewed companies and minor changed were made, but those did not affect the concluded end results.

The second criteria raised by Mäkelä (1990, 47) was the sufficiency of material. When it comes to qualitative research a simple rule does not exist on what is enough empirical data for a trustworthy study. On the one hand, a too narrow set of material does not offer a comprehensive overview required for in-depth analysis of the research, but on the other hand too much of gathered information may suffocate the essential findings in the excess of material. The general rule is to gather more data for the point when no new findings appear even when more material is gathered. In this research this point was already reached after three interviews but this was not the only reason for having this small number of interviews. The basic rule of sufficiency of material provided the acceptance to trust that these three interviews provided enough information for this thesis. (Mäkelä 1990, 52; Eriksson & Kovalainen 2008, 97–99.) Three interviews are still a very short collection of data and it might be that this has led the empirical findings to a complete opposing direction on how spare parts are managed in Finnish high-tech companies.

The coverage of the material was stated as the third criteria by Mäkelä (1990, 47) meaning that the researchers' conclusions and findings should not be depend on not rational selections out of a transcript but by using the same criteria when going through all of the collected material. He also raises the importance to determine in advance how large empirical gathered materials are processed so that all of them can be evaluated in the same way and are in a controllable form. The reason for this is that the materials are often comprehensive and difficult to manage. (Mäkelä 1990, 53.) In this research most of the findings are justified by using several pieces of material and those which have had only one source backing the finding up are clearly mentioned to have this kind of justification. In this research, the aim was to include different viewpoints on the topic to create later a variety of diverse scenarios on the subject and also more objectivity about the topic. It should also be noted that only few interviews offer remarkable challenges to conclude holistic findings of the studied research question. With this number of interviews even one different opinion among the answers can change the whole majority opinion of the gathered findings and most conclusions are made based on these small majorities in the analysis phase.

As the last criteria Mäkelä (1990, 47) expresses the ability to evaluate the analysis and the repeatability of it. By the ability to evaluate the analysis Mäkelä means the individual's readiness who is reading the research to weight critically the provided reasoning of the research and that the reader is given the qualifications to conclude his or her own opinion with the presented findings in the study. This thesis provides reasoning on the made decisions on choices regarding the used methods, data collection and analysis.

The repeatability of the analysis means that anyone who conduct this same research could make the same analysis again and get the same outcomes by following the exact same methods and perceptions that were used in this study. It is most likely that the repetition of this research would be difficult. The usage of the same methods would provide the same conclusion but the sources might be outdated already in the near future because of the rapid evolution of the researched topic. The research can be conducted in the same way but it has to be noted that when this research was made the topic was still evolving and the future of this topic might change radically in the future and it changes the situation which existed in this research. (Mäkelä 1990, 53–54.)

6 ANALYSIS OF THE CURRENT STATE ON SPARE PART BUSINESS AND ADDITIVE MANUFACTURING

This chapter presents and analyses the result which were gained from the accomplished interviews and reflect these findings to the earlier presented theoretical frameworks of spare part management, additive manufacturing and the created theoretical framework. Only the findings which discussed the topic on some way are shown and found theory on the specific finding is shortly reviewed.

6.1 Management of spare parts in Finnish high-tech companies

The interviewed companies were asked how their spare parts are managed at the moment and it provided different approaches to the topic. The companies A and B explained their management on a more logistical point of view ranging from sourcing the spare parts to the distribution of them. The company C explained more the whole process and how the whole process starts from the actual request for a quote until the end supplying of the spare parts. All of the companies opened their process on a general level and the processes were almost identical among the companies. It was stated by Duchessi et al. (1988, 9.) that the management of spare parts different from regular material management but this was not expressed directly in any of the interview. Although in some cases it was noted that there are differences when it comes to spare parts and the management of them has evolved during the resent years.

It was found that all organizations A, B and C had a process in which the global or central office was in charge of the documentation of the offered spare parts and their local sales offices were in charge of each individual market areas specific customers. The company C explained their process in identifying needed spare parts: Step by step different departments were contacted if there were issues regarding the wanted spare parts and in the end the global office provided the local market area the needed information for a quote. The company B in turn offers and supplies spare parts from their central organization to local organizations but these frontline offices are in addition allowed to purchase the same spare parts from the same supplier or source the spare parts on a local level. When the frontline offices buy the spare parts from the central office, they have to pay an internal markup and in turn the central organization has to prove the local offices that they provide these spare parts in the easiest, fastest and most reliable way. They estimated that the amount of centrally sold spare parts count for around 70 to 80 per cent of total spare part sales inside the whole organization. The company A in turn made almost all of the purchasing, stocking and supplying to local offices from one global warehouse. In addition, they had one regional warehouse for stocking and for high running and local items they have local smaller stocks including local office stocks, service vans and even local dealers' stocks.

So, it can be seen that in these three organizations the spare parts are mostly sourced and documented on a central level but it is possible in some cases that the local office is allowed to source the needed spare parts on their own. It was argued in multiple academic publications (Cohen et al. 2016, 133–134; van der Heijden & Zijm 2016, 917; Wagner et al. 2012, 89) that organizations should decide between central and decentral choices when it comes to inventories and deliveries but in this case the company B has added the local sourcing to it and to company is making a complete mixture on each level on these possible directions. The companies A and B in addition provided insight on their sourcing strategies and why spare parts are not manufactured by the company. Company B said:

> *"And I'm at the technical side here. So, I think we have around about 200 000 spare parts available today. About 50 000 are stocked in Germany but of course we have also stock locations in China and in Singapore. And about 1000 different suppliers. Because of course we don't manufacture everything ourselves." (Director, Maintenance Field Support - Company B)*

For this reason, it would be impossible to manufacture all those spare parts by themselves. The company A in turn relies on the same suppliers in the project phase and also if possible when purchasing spare parts. This is because the volumes are much higher in this way which in turn decreases costs and it was furthermore reasoned that it is resource draining to source new suppliers and make the needed testing for the newly acquired spare parts. Company B sourced typically all the needed spare parts from supplier who were located either close to their global warehouse or to their multi-assembly units and by close it can in same cases mean even a range inside the same continent. It was not clearly stated how many suppliers the company A had and if company B had substitutive suppliers for their parts but Roda et al. (2014, 530) argued that the shorter the amount of part suppliers is the more, they have negotiation power towards the company when it comes to prices and lead times. In addition, the findings from Cohen et al. (2016, 133–134) aligned with the sourcing strategy of company A pointing out that closer located suppliers decrease lead times and transportation costs. The types of the suppliers were not mentioned during the interviews, but it was told that the companies purchased commercial parts and parts whose design they owned. These kinds of suppliers were mentioned in the theoretical part.

Company B describes their sourcing and suppliers as follows: The company manufactures some of the needed parts by them self but most of the parts are manufactured by suppliers. For certain more complex parts the company uses specific suppliers, but they are developed internally, and the manufacturing is outsourced. For basic components it varies if already existing components from suppliers can be used or are those components also designed inside the company. So most of these components are manufactured outside the company and usually the design and development belong to the company.

All companies were asked if they manufacture spare parts by themselves and it provided the information that none of the interviewed companies manufactured all of their spare parts by themselves. Cohen et al. (2006, 263) and Wagner et al. (2012, 78–80) showed that there are different options on how to get the needed spare parts. Company A had outsourced the manufacturing years ago to their suppliers, but the companies B and C had some of manufacturing still in their own premises. Both companies A and B told that they have factories for assembling products, but these are not used for spare parts, but company B said that there can be exceptions for special products which need internal manufacturing, but these cases are rare. Ways like repairing broken spare parts, using second hand spare parts or to redesign the machine (Cohen et al. 2006, 263; van der Heijden & Zijm 2016, 918; Behfard et al. 2015, 498) were not mentioned in the interviews. It can be seen that all of the companies relied on sourcing almost all of their spare parts from outside of the firm. Reason for using external supplier were the enormous amount of spare parts and strategy changes in manufacturing. Production factories existed but these were used for only in rare cases for manufacturing spare parts because they were meant for assembling end products. A clear reason for this can be that the companies focus on their core business and the assembling needs special knowledge which only the specific company owns.

The logistics and especially the inventories of spare parts were managed in different ways. All of the companies had central warehouses which were mostly used at some point in the spare part deliveries. The company B in turn had three main storage locations but they have also additional 15 000 storage locations ranging from individual stocks in suitcases, at service vans, offices and warehouses. Only the three main storages are controlled from the central unit. Company A had one global and regional warehouse and like be multiple range of smaller stocks for fast moving parts. Company C had also three main warehouses and each of their local office had their own stocks in addition. These local market offices are in charge of their inventories and they have visibility to the main global warehouse stocks. It can be noted that all interviewed companies had a similar warehousing strategy including centralized main warehouses including smaller decentralized stocks for spare parts. This can be seen that spare part management follows a mixture between central and decentral warehousing strategy. Centralizing inventories was seen as a possible choice by Wagner et al. (2012, 86) because it was seen more efficient stock management. Cohen et al. (2006, 262–263) suggested that central locations possess the main inventory of spare parts and when needed smaller storage locations can use these global warehouses for ordering spares which was clearly the case for the companies B and C. A clear motive for centralizing spare part inventories were not given during the interviews but Zanovani et al. (2005, 1) and Wagner et al. (2012, 77) provide an explanation. Centralized inventories decrease inventory costs and make business more profitable according to found theory and this can be assumed to be a reason why these companies have at least on some level centralized their inventories.

Also, Company B explained that they have visibility on all the stocks worldwide and these could be used if there would be an urgent need for a specific spare part but usually the fulfilment plants (global warehouses) should be used in the first place for orders. This way of acting was supported by Kranenburg and Houtum (2008, 947) to use various sourcing channels if the original one is not acceptable for some reason. The control of the local stocks belongs to the local organization which is the same case for the company C. The company C mentioned that they have some inventory for regular spares, but it varies based on specific technology which the products belong to. The company A in turn manages all of their warehouses and they have invested resources to their inventory and logistics management recently and this has evolved a lot during the last years. Because the inventory management in the company B is done in each local organization by themselves there are huge differences in the visibility and efficiency of those stocks. Wagner et al. (2012, 69) raised the management of spare part inventories as a possible competition advantage and that inventories can drain resources out of the company if they are managed poorly. Because Company A has invested into the inventory management, they will most likely profit from this investment in the long run. There can be seen differences in the management strategies among the companies even though the basic concept of warehousing strategies is similar. Two companies B and C had similar management strategies and they are bigger in size compared to the company A, which might be the reason for this. With more spare parts to be managed it can be more efficient to divide control over storage locations to ensure efficient stock management.

In addition, company A mentioned that to ensure shorter delivery times for spare parts they have intended to start direct deliveries from the supplier towards the end customer. This would be important for situations were part failure results in breakdowns for the customer. Company C has already direct deliveries to the customer and local offices, but these are only used if this can decrease delivery times notably or if the ordered parts are huge in size. Shorter delivery times were seen as an advantage among competition and they create better value towards to customer and increase customer satisfaction and loyalty. Because this possibility of direct deliveries was mentioned it seems that in some cases the decreasing of delivery times is evident to ensure better service quality towards the customer. Furthermore, company B raised their possibility to return commercial parts back to the supplier if they are not needed which in turn makes their inventories more flexible. This in turn shows good service quality in the different way from the supplier of the spare parts. This kind of backwards supplying was not found in the chapters 2 and 3 but it clearly makes the companies inventories more adaptable.

When it comes to sourcing and inventory management of spare parts, the academic publications (Cohen et al. 2006, 262–263; Wagner et al. 2012, 86; van der Heijden & Zijm 2016, 918; Zanovani et al. 2005, 1; Kranenburg and Houtum 2008, 947) and empirical findings are in most cases in line. There were some findings in the chapter 2.1–2.3 (Duchessi et al. 1988, 10; Roda et al. 2014, 530; Duchessi et al. 1988, 9; Cohen et al. 2016, 130, 138) which did not come up during the interviews like supplying scarce resources first to prime customers and obsolete spare parts in inventories. There were clearly a lot in common between the interviewed companies but also some differences in strategic choices on storage locations, sourcing policies and management policies of stocks based on the hold interviews. Inside the theoretical framework (Figure 3) for these topics there were not just a single right strategy suggested. It was more depending on each unique situation and the organizations own choices and strategy.

Only company B highlighted the importance of the documentation of spare parts and this is already made during the project phase which in turn makes it easier to purchase spare parts in the future. Spare parts need good technical data, documentation and catalogues so that they can be provided smoothly for maintenance and repairs around the world. All of these arguments were also provided by Pfohl and Ester (1999, 5) because the management of an enormous count of spare parts is already challenging with good documentation. In addition, for spare parts which are not for the company B's own equipment, there is a special team who investigate these spares and create the needed documentation for these parts. Then they can also be sold for the needed equipment even though it is not sold by them. Additionally, they mentioned the commercial spare parts which are dependent on the suppliers' offerings. New needs of commercial spare parts can generate and then these parts are updated by the supplier and in the company's offerings and afterwards these can be sold and shipped accordingly. This point was notable because Cohen et al. (2006, 263) only suggested to use spares from different machines but it did not suggest maintaining equipment sold by other parties.

When it comes to the manufacturing among these three companies it can be seen that none of them manufactures all of their spare parts due of the countless number of them. Suppliers are used to provide the manufacturing of the spare parts and this in turn increases the role of supply chain management inside the companies. If the customers of the companies act proactively then they can order spare parts before the actual need occurs. This is not always the case because external factors might cause part failure and then the spare parts are needed as soon as possible. Also, because nowadays supply chains are managed so efficiently that stocks are minimized, delays in deliveries and production can have costly outcomes. Every one of the interviewed companies used commercial spare parts in their own equipment and when it came to their owned designs, outsourcing the manufacturing of these parts was a general choice. The assembling of new sold products was still made by the companies but spare parts in most cases were just ordered from the supplier and send forward to the subscriber.

6.2 The aftermarkets and spare parts

It was emphasized previously that the role of spare parts has been changing from a legal obligation towards a reliable profit maker in all economic situations. The empirical findings support this statement. All the interviewed organizations raised the important role of spare parts in their business. The company A described spare parts as a profit maker even in hard economic times and they can be seen as a corner stone of their company. They noted that in earlier times spare parts might have been seen as a necessary evil but nowadays they are a vital part of their business strategy generating steady inflows of revenue. It was noted by them that even though services and other immaterial additions are attached to spare parts the profitability comes from the physical parts.

> *"Services are developed and added to spare parts, but the profitability comes from selling spare parts." (Director, Special projects - Company A)*

The company B revealed that the whole maintenance business makes around the half of their revenue and spare parts itself count for 50 per cent of this revenue inflow although it is hard to estimate the exact amount of it. As an example of this, company B mentioned that spare parts are not always sold purely as spare parts, but they are included in maintenance contract and uptime agreements. Wagner et al. (2012, 69–70, 81.) estimation was in align with this proposed rate between spare parts and the overall revenues and the additional included services were mentioned in the theoretical phase of this thesis.

Company C also agrees that spare parts are an important sector of the company's business and it is seen as a profitable part of the business. In addition, C raised that the importance of spare parts has increased due to company acquisitions during the years. The importance of spare parts has grown during the decades, but they have had a smaller focus earlier in the company's strategy about it. Chapters 2 and 3 did not provided the finding about acquisitions increasing the amount of spare part sales but this can be assumed as a larger equipment base which in turn supported the idea of increased spare part sales. This goes hand in hand with the company A suggestion that the demand for spare parts will raise in the future along the sold machines, but company C did not assume that the need for spare parts will increase or decrease in the future. This can be seen as the ratio between demand and the install base will not change in the coming years. Company B sees that megatrends, urbanization and aging population increase their service and spare part sales.

Furthermore, they see that even when parts would be made more durable in the coming years there are so many new products sold on a yearly base so that the amount of demand for spare parts will raise during the next decades. Moreover, if parts are stronger than ever before there are still tear and wear parts which wear off during time and parts might brake because of external mistakes which need also to be changed to new ones. Furthermore, the need to upgrade and modernize old equipment is seen by B to increase spare part demand which was seen by Öner et al. (2007) and Heijden and Zijm (2016, 915–916) as mostly difficult and costly to execute.

The demand of spare parts was described as intermittent and hard to be predicted and this was found also in the interviews. All of the companies are predicting spare part demand on some level. The company C revealed that they are able to foresee the demand to some degree. In turn the companies A and B reported that they use software which assist in the prediction and these programs use historical data and patterns and besides predictions were made in the company A based on sold equipment. This company also noted that the predictions based on sold equipment provide numbers which are just theoretical and those can be used as help in strategic planning. The company B explained that it is very difficult to predict future demand but with good proactive operations and good communication with local offices spare parts can be ordered in advance for becoming needs. Different ways of prediction future demand existed among the companies, but all did it on some level. Syntetos et al. (2009, 311–312.) support that for forecasting demand it is vital to be familiar with demand mechanisms. In addition, the Simao and Powell (2009, 156) and Roda et al. (2014, 520–521) included challenging situations like new machines without historical data and environmental factors which make the prediction of future demand complicated.

Competition inside the spare part markets existed according to the interviewed firms but it was different for all of them. Company A saw that there is existing competition when it comes to basic components but for critical spare parts the customers were seen as loyal for the firm and to avoid risks, they return to the original supplier for spare parts. The competition was seen bigger in the equipment market in which competition was identified. Company B's competition is more complex. Inside their industry competitors are forced to buy the spare parts from the organization and it goes also the opposite on the European market. So, the maintenance service providers have to compete on a different service level. The competition among equipment providers is very strong which make the role of service pricing evident. Where these spares are bought, what is the quality and the organizations philosophy are factors which make the difference in competition according to the firm B.

> *"It is important to offer the customers something extra than just the spares to ensure that they will return to the company." (Director, Maintenance Field Support - Company B)*

Wagner et al. (2012, 78, 82.) saw competition to exist on spare part markets because of high profits. The reasons why customers choose the spare part suppliers were slightly different then the empirical findings. Better after sales services was one reason and it can be interpreted that also the companies agree with this statement. Another factor stated by Wagner et al. (2012, 78–89) was the price which in turn was not agreed by the firms. It was mentioned that too high prices might affect spare part sales in a negative manner but for critical parts the customers were loyal towards to the companies. It can be concluded that pricing affects standard and commercial parts which are not vital for the equipment. Additional services were also seen as a competitive advantage according to Davies (2004, 731) and also in practice.

The company A was also asked about legal obligations to provide spare parts for their customer. These obligations varied based on customers from normally 10 years to special clients to which spares part deliveries might be up to 25 years. Wagner et al. (2012, 69–70, 81.) supported this finding and saw that spare part sales after these obligations will increase customer loyalty. The company raised the problem if there has been produced only a limited number of sold equipment and the obligations tie them up to serve these scarce spare parts for even a decade. A described the spare part markets as niche markets which are not easily entered for most of their business lines and there are only few suppliers. For tear and wear parts there has been traditionally competition from local around the corner shops.

Chapter 2.1 and empirical findings on categorizing spare parts have on one hand some similarities but on the other hand differences. The companies A, B and C brought up that their spare parts are categorized in multiple ways and one uniting criterion was the criticality which was also mentioned by Deduja (2014, 24). In addition to this Duchessi et al. (1988, 8) suggested that spare parts could be categorized according to stock costs which was measured in most of the interviewed companies, but it was not mentioned to be a categorizing factor. In addition, the companies told following categorizing criteria. Company A can either categorize the spare parts according for the reason of change including annual changes, wear parts and part failures because of external reasons or based on purchasing groups where materials are categorized on a sourcing level. C in turn also uses sourcing for categorizing but spare parts are also divided based on pricing rules inside the company. The company B revealed the most categories adding to the earlier mentioned ones categorizing factors like: technicality, intellectual property, criticality, stocked or no stocked, consumption, and commercial. Company A mentioned that parts which can only be purchased from them are not over prized so that customers do not experience a negative feeling towards these company owned spare parts. Findings showed that there are different ways of categorizing spare parts and the same spare part can belong to different categories at the same time.

When it comes to critical spare parts all of the interviewed companies had stocks for them. This goes in line with the found by Duchessi et al. (1988, 8) that critical spare parts are kept in stocks to prevent and shorten expensive breakdowns of production equipment. Company A reported that they can request critical spares out of their own equipment production if really needed. Stocking of these spares was seen evident but each individual stock needs some kind of turnover rate to make the business profitable. Although they have the possibility to use supplier stocks for critical spare parts, they must have some predictable turnover rates. In contrast B had stocks for critical spare parts even when they had none turnover but these parts are always ready to be shipped immediately when needed. The companies provided information on how their critical spare parts are managed and explained on a general level what are critical parts for them and in all cases as critical spare parts were listed those which could result in breakdowns and system failures are the customers end. Roda et al, (2014, 531) listed additionally that criticality can be seen in maintenance, financial and logistical perspectives. Critical spares had the same philosophy that they are for someone a must to kept in stock but if the turnover speed is slow it is not profitable for the company. Based on the held interviews it can also be noted that resources are put into the management of critical spare parts which was also seen in Duchessi et al. (1988, 9) as an important point.

For these Finnish organizations the role of spare parts has changed during the years and it is now seen as an important part of their strategies. The size of the spare part markets can be seen as growing alongside the equipment base increases but if counting out modernizations and upgrades, the relative amount between sold products and spare parts is not going to change in the coming years radically. They are seen as profit makers but the nature of intermittent demand challenges the spare part management but safety stocks were used to confront demand on critical spare parts. These stocks are expensive to manage and they tie enormous amounts of money in them but to minimize breakdown costs these stocks are evident for the companies.

6.3 Additive manufacturing in the industry

Questions about additive manufacturing and how the firms think about it were asked during the interviews. All of the companies have had this technology as a topic on some level. Company A have been thinking about two options: Source suppliers who manufacture with this manufacturing method or invest by themselves to additive manufacturing capacity. The company C in turn has had discussion about additive manufacturing but at the moment for the researched product family additive manufacturing is not seen as a relevant option. The company B has had thoughts about it and they have been already investing in to the research of it. They see the possibilities in it and the development of this technology is seen promising.

> *"It is the future. And the technology is there, the 3D printings is developing very rapidly. So what cannot be printed last year might be possible this year or maybe possible after five years" (Director, Maintenance Field Support - Company B)*

They have investigated the technical and economical specifications on the technology and already prepared 3500 products one year ago to possibly be printed with additive manufacturing. When the interview was conducted, they were already waiting for the first test result on produced components but the AM was still seen expensive and the produced parts need still testing. All of the companies had different approaches on the possible implementation of this technology and the state ranged from investigating possible options to already testing produced parts.

All of the companies see the benefits of additive manufacturing in shortening delivery times of components but in addition company A raise the possibility to decreasing inventories with additive manufacturing and also the readiness to sell no stock units instantly to customer. All these possible advantages were also supported by Holmström (2004), Khajavi et al. (2014, 50) and Holmström and Partanen (2014, 423) from multiple aspects. Company A mentioned also that additive manufacturing could even change their business strategy to include as well own manufacturing of spare parts with AM. The amount of different spare parts, supplier, used materials, drawings and molds are reasons why company B sees additive manufacturing as a possibility. They found it furthermore interesting that parts which need special molds which do not exist anymore could be still printed and expensive re-produced molds would not be needed for these cases. They even liked the idea of not having to invest into inventories of products but into product specific data:

> *"You don't actually spend anything by having more and more data in your hard drive. And by having a 3D-printer available it is a one-time investment" (Director, Supply Chain Operations - Company B)*

Company B recognizes also the new possibilities on a component design level. Lighter and stronger components could be developed already in the project phase by creating the components inside with different structures and make the existing equipment more energy efficient and stronger. They see AM technologies as greener compared to traditional manufacturing methods and if transportation can be reduced it decreases the environmental impact of the organization. These two remarks from the company B have been identified as well by Ford and Despeisse (2016, 1574) although the findings on the ecological assumptions were not undisputed (Faludi et al. 2015, 26). There are existing different motives for the change to start using additive manufacturing but shorter delivery times and more accurate deliveries raised as a connective attribute among the interviews.

The following findings about additive manufacturing were not found in the theoretical framework but they basically in align to each other. The change from more traditional manufacturing methods toward additive manufacturing of components is seen in every company as a resource draining and time consuming transition. Company B pointed out that 3D-cut models are needed for production and only the components created during the last year have them available right now. Company A had a different approach for this. They saw that the shift would be fast if they would use an external supplier who would manufacture the components. Although the manufactured components would need a certain amount of testing, for none safety hazardous components the manufacturers certificates would be enough. These suitable components would be manufactured either out of plastic or metal. If company A would invest in own manufacturing equipment this would already take time in cost-analyses and they would need to develop supporting activities for the technology. The same company brought the idea up that one option for them could be a co-investment AM equipment with a some of their current suppliers.

Company C approaches the manufacturing of spare parts with AM in a different aspect. They state that the spare parts should be designed already in the equipment's project phase so that spare parts could be manufactured using AM technologies and be suitable for the specific equipment. The shift from existing equipment's spare parts would take years of work to be transformed as AM adaptable. It would not be profitable in the sense that AM manufactured spare parts would also be more expensive and the change is there for not seen profitable. Company C argues that different materials are more suitable for this transition but the environment to which the spare parts are used plays a crucial role of adaptivity. They conclude that possible spare parts would be those which are made of plastic and which are only rarely needed. Sasson and Johnson (2016, 91) had the same ideas that AM is more suitable for low volume production. Even though the answers were different among each other, there can be seen that right documentation is evident to get additive manufacturing to the spare part business based on the findings.

The company B said that even when only one or two per cent of their spare parts would be suitable for AM production it is still seen as interesting choice to be considered and this amount of suitable spare parts might even improve over the years up to five per cent. AM would be feasible for parts made of plastic which are no more in regular production and in which the exterior does not play an important role. Section 3.3 saw production colors, precision and product surface as key challenges of AM and the poor visual qualities of produced parts with AM are seen as a negative feature as well by the company B.

So the companies identified that the testing of AM manufactured parts is a factor which makes the adaption of this technology difficult. Company C argues that the benefits from the change to additive manufacturing would also be hard to measure. Although B sees that they will have this technology in experimental use inside five years, their strategy will not rely on it even then. All noted that that plastic as the used raw material was among the suitable ones for production which can be reflected to Atzeni and Salmi (2012, 1147) who suggested that other materials compared to plastic are still not on the same level when it comes to additive manufacturing components. Technical issues can be identified to be a problem in the adaptation of additive manufacturing, which was also listed as an important factor to evolve in the theoretical framework (Figure 3).

It was surprising that companies A and B explained that their products are hard to copy even when using scanning technologies on already produced spare parts. Company A do not believe that their customers would start manufacturing spare parts with AM by themselves because their focus would be still in their core business and most of them are relatively small in size. They saw it plausible that if AM equipment's costs decrease in coming years there might be more competition on the spare part market but still it is seen unlikely. When the companies B and C were asked if they see additive manufacturing as a threat when it comes to copying products both responded that they do not think that there will be a radical change for the present situation which was presented otherwise by Holmström and Partanen (2014, 425–426). It suggested that the evolution of AM would raise new problems regarding IP-rights. Spare parts are copied already from both firms. Company C sees the copying as a small harm and spectates the clients in a bigger picture:

> *" At least the end customer is always our customer. Is it worth to claim about small patent violations? It can harm other business which hast to be considered always" (Commercial product Manager - Company C)*

Company B in turn knows that some of the basic parts are already copied but for the more complex parts they do not see AM technologies possible to violate their IP-rights. External copying of parts revealed not to be a problem among the organizations and it was not recognized that additive manufacturing could create threats in the future. Figure 3 included the external factor legislation and based on these findings the importance of the factor might not be as high as expected.

The option that the spare parts would be produced by suppliers with AM was not excluded. Company A realized that some of their suppliers are larger than them and they might have more resources for investing in AM but it would depend fully on the spare part sourcing category. Company C in turn states that it must be in the suppliers' interest to change production towards AM and the company itself cannot promise the needed demand for the supplier for these parts. They saw AM more reasonable for companies who produce mass products rather than unique equipment and they are not aware that any of their suppliers would use AM for the ordered spare parts at the moment. This is the opposite to Petrick and Simpson (2013, 15) who argued that AM is suitable for more customized, low-volume and complex parts. Furthermore, it is the opposite for company B which have already heard about parts produced with AM, but the prices have been still so high that they have not made any purchases on parts which are additive manufactured yet. Findings show hints that the adaptation of additive manufacturing is in a more advanced state among supplier. This might be because their core business is in the manufacturing of sold spare parts which is not the case among the interviewed organizations.

The best ability of additive manufacturing was seen in the chance of decreasing delivery times among all the interviews. This came up during each interview multiple times and in many forms. Multiple academic publications identified also that AM will affect logistics by decreasing inventory levels and delivery times. Company A sees that AM has the potential to reshape supply chains in their operations but in the end, it could not remove the need for inventories fully. Company B in turn figures that AM could be used as an extra safety measure for stockouts. If there would have been bad inventory planning for instance, AM could be used as a backup until the original supplier could delivered the traditionally manufactured spare parts and AM could also decrease the amount of needed spare parts in inventories making them more flexible for actual demand.

In addition, company C identified two ways on how AM could additionally decrease delivery times and make additive manufacturing more profitable: The equipment should be located in several globally diverse locations and production capacity should be centralized according to the used raw material in the manufacturing machines. Petrick and Simpson (2013, 15), Khajavi et al. (2014, 39) and Holmstöm et al. (2010, 691) provided multiple suggestions on centralizing manufacturing and on the choice of location, but the centralizing of manufacturing based on the used raw material was not brought up.

The likelihood of selling licenses to customers and let them handle AM was seen unlikely. Company C brought up that they still have the technical responsibility to deliver the right spare parts and it would be impossible to control the situation if clients could manufacture the corporates owned spare parts by themselves. They also noted that they as well have a countless number of clients that the gained profits would be minimal. Company B in turn sees a small possibility in it but they note that the volumes would be too small and the benefits from AM come from the additional flexibility and not from high volumes. Mellor et al. (2014, 195.) findings backed up these thoughts and stated that AM is convenient to fabricate small or medium batches. Company B raised up the plausibility for companies which specializes in additive manufacturing and they could manufacture the needed parts if needed.

The future of the combination of additive manufacturing and spare parts was seen more as a possibility which should be researched but not as evident on a general level. Company

A sees that AM has to be more cost efficient to take bigger shares in manufacturing. Company B noted that years ago mobile telephones evolution was exponential, and it changed the whole industry so they do not rule AM out and will wait how it will progress.

> *"Well if I think about telephones from 10 years ago or 15 years ago to today. It's a world of difference. So if I take that little bit into consideration that how fast technology can develop, I think at least definitely partly it could replace traditional manufacturing" (Director, Maintenance Field Support - Company B)*

They even brought up the fact that other manufacturing technologies are evolving at the same time and those will affect the adaption of AM. Gibson (2016, 17) however saw that AM will co-develop with these other technologies and it might create completely new solutions. Company A relays on the possible evolution of AM and they would be disappointed if it did not affect the spare part business on any level. Company C on the other side found that the spare part business will evolve in general because of better documentation and better supporting systems but AM will not change it in any radical way.

> *"In itself technological reformations have changed other industries in a radical way, so why shouldn't it change also spare part business?" (Director, Special projects - Company A)*

The companies B and C stated that break downs can cost huge amounts of money ranging from thousands to millions of euros and in these cases rapid deliveries are a must. It does not matter if the production will be more expensive if the whole machine or factory is not running due of a single part failure and in these cases, AM could be suitable and provide flexibility to manufacturing times. Section 4.1 suggest the same ideas that with AM it is possible to be more efficient on selling customers better uptimes of equipment due of decreased delivery times.

> *" If you think about it that if a production facility or equipment is not running because you don't have the spare part the losses for the customer can be tens of millions, millions or hundreds of thousands of euros. Then it doesn't matter if you get the spare part fast at the place if it's more expensive in the end." (Commercial product Manager - Company C)*

There are also deficiencies which company B and C identify in AM. Company B emphasizes that additive manufacturing machines are not capable to produce electrical components and circuit boards which the company uses and furthermore the parts would still need the assembling process. Weller et al. (2015, 53–54) in opposite suggested that it is already possible to manufacture whole assemblies in one production run and even the possibility to produce electrical components by using multiple raw materials in the manufacturing was noted (Glassschroeder et al. 2015, 214) although microelectronics was seen as not printable yet (Ford & Despeisse 2016, 1578). Company C in turn pointed out that AM would be adaptable for standard machine component production but not for production equipment or for their industry in a notable way. Also, these findings can be linked to the figure 3 technical factor. The organizations saw the disadvantages of additive manufacturing in technical issues which make the integration of AM to their business at the moment unlikely.

Company A identifies that AM could provide them an advantage in competition if they would be among the first movers to this technology, but this would need a change in their organizations core strategy. They see that it would affect their sourcing strategies as well and there is a possibility to new competition on the spare part markets. They mentioned that companies inside the logistics industry have already invested in to this new technology because it might make radical changes to their core business model. The part 4.4 of this thesis raised the possibility of new business models around AM and spare parts but it was more on new businesses and not what A suggested the existing business models would change in a so dramatic way. In addition, company B saw some of their spare parts adaptable for additive manufacturing and when they were asked about it, they replied following:

> *"Yes! I can see that. That's why we are stepping in now in this technology world. Because we see there the future in it. And it's better to step in early than in say in after 8 to 10 years we are too late." (Director, Maintenance Field Support - Company B)*

It can be seen that with the current level of additive manufacturing Finnish companies identify the possible benefits of additive manufacturing to come from reshaping supply chains. Spare parts are sometimes needed urgently to ensure equipment uptime and if spare parts have the needed documentation behind them can additive manufacturing decrease delivery times and ensure better uptime for the customers. The manufacturing technology was still seen as expensive and all needed work to convert existing files to AM adaptable was seen not profitable in most cases. Quality issues and challenging environments were raised as obstacles and comparing additive manufacturing to traditional manufacturing methods, additive manufacturing had still not so many advantages. The possible evolution of this technology left still place for optimistic toughs on how it could change the spare part business in a more radical way but this was still not seen as likely in the following years.

6.4 Future scenarios on additive manufacturing & spare parts

In this section are the values for the table 3 shown and three different scenarios about additive manufacturing and spare parts management presented. Three scenarios are sufficient to provide a good overlook on the plausible outcomes of the combination of additive manufacturing and spare part management, but the values can be used to create more possibilities if wanted. The table 4 values are based on the PESTEL analysis and the conducted literature review.

Table 4 Macro environmental background

PESTEL & AM	A	B	C
Global political state	Stable	Slightly unstable	Trade restrictions
New investments in equipment and machines	Increasing	Decreasing	Stagnate
Wages in East-Asia and working conditions	Wages raising	Healthy working environment important	Nothing has changed
Copying products and other technologies	Easy to copy	Hard to copy	Alternative technologies
Concerns and attitudes toward climate change	Individuals responsible and growing	Existing but not so important	Manufacturers seen responsible
Legislation concerning additive manufacturing	UpToDate and strict in manufacturing	Piracy impossible to control	Almost sufficient
The capabilities of AM technology	All kind of spare parts and assemblies can be manufactured but it is expensive	Metallic and plastic parts can be manufactured with good quality and it is profitable	Small spare parts with microcircuits can be manufactured for reasonable prices

Table 4 is used to create changing environments for each individual scenario. The column PESTEL & AM include external factors which were identified in the chapter 4.5 and the columns A, B and C include possible outcomes of each of the identified external factor. The environmental backgrounds are created so that each scenario has one outcome of the factors and they are chosen to create as diverse backgrounds as possible however in the way that they are plausible and not dissonant internally. Each specific environment is named after the path take go inside the table forming a seven-letter code. Table 5 lists strategic choices and the nature of competition on the spare part markets.

Table 5 Strategic choices among spare part management and competition

	D	E	F
Fabrication with additive manufacturing	Multiple AM machines run at the same time	AM manufacturing only if needed	Co-operation inside the network due of high investments
Inventories of spare parts	Existing but more flexible	Smaller but existing	Different stock for AM raw material
Additive manufacturing equipment location	Decentral	Central	Supplier
Legal obligation to provide spare parts for customers	Exists toward customers	Decreasing*	Changing to sell uptime for customers*
Competition inside the spare part market	Competition only for standard and low profit spare parts	Increasing	No radical changes

* These outcomes were not mentioned during the interviews, but they were included in the literary review

The findings in the table 5 are based on the conducted interviews and the literature review. They show three different outcomes for each statement in the first column. These plausible outcomes are used to create strategies about spare parts management with additive manufacturing for organizations in the scenarios. Also, in this case the strategy includes one possible outcome from each row and they are formed so that they are not in dissonant internally. They are also generated so that they fit each specific environment which are first created based on the table 4. This results in unique bases for each scenario which include the 12-letter code for background information (ABC from the table 4 and DEF from the table 5). The scenarios alternative environments and plausible spare part strategies are:

- BCABACA EDEEE Company 1
- CBCACBB DFDFD Company 2
- AABCBAC FEFDF Company 3

Each scenario starts by identifying the environment in which the organization is performing and is followed by motives and explanations on their spare part business strategy and what has led to the made choices. The scenarios are timed to happen in the year 2030 and all of the scenarios are for Finnish high-tech organizations who have global trade and have been sourcing spare parts earlier from outside suppliers. A basic assumption in each of these cases was that additive manufacturing is on some level integrated to the spare part business.

6.4.1 Scenario 1 – Additive manufacturing is used to decrease stock sizes and increase supply chain efficiency

In the first scenario the overall global political state is seen unstable, but there are no radical political choices made which would affect the manufacturing industry directly. Organizations make still investments in their manufacturing equipment, but the amount is not increasing or decreasing in a notable form. Global supply chains are working almost on a normal level but there are some global trends which affect manufacturing indirectly. Wages are increasing in those countries, which have earlier been chosen for mass production due of smaller labor and manufacturing costs and for this reason, organizations are reorganizing their global supply chains. There are no trade restrictions among countries but changes in global politics affect oil prices, which increase transportation costs and make closer located suppliers a more suitable choice. In addition, some countries are increasing importing taxes and customs clearances between continents are taking more time. These actions are slowly affecting the international trade in the way that continental and more domestic supply chains are favored compared to global supply chains. Additive manufacturing is seen for the company 1 as a tempting choice because it decreases the effects of raising logistical costs and if manufacturing equipment is located to different central warehouses, taxes and customs can also be avoided at some level.

Awareness towards climate is growing and individual consumers have taken responsibility to decrease emissions by changing their own consuming attitudes. Companies who act environmentally friendly are favored between end customers, but it has not affected the B2B-decisions yet in a notable way. Additive manufacturing can be seen as a greener manufacturing method if the used energy source is renewable, but eco-friendly production is not profitable and not seen as a competitive advantage inside the industry. This is because additive manufacturing is still more expensive than traditional manufacturing methods and the profitability has to raise to a better level so that traditional manufacturing could be replaced in a wider scope.

Copying technologies have not developed much during the years and the copying of existing spare parts with scanning technologies is not profitable because of poor quality and low accuracy in the produced copies. Competition inside the spare part market is raising although the overall legislation in IP-rights is on an almost sufficient level but high margins and illegal manufactured copies of uncomplex parts are increasing competition in the spare part markets. Companies have to gain a competitive advantage with faster and more accurate delivery times and by decreasing overall costs in the spare part supply chains. Because there are more spare part providers on the markets, customers are not willing to tie them up to the same company for a longer period and obligations to supply spare parts for customers are declining.

Even though additive manufacturing is still more expensive than subtractive manufacturing methods, it has evolved to the point that almost everything can be printed with it. Assemblies can be manufactured in one manufacturing run and broken parts can be in some cases get temporary fixed by using additive manufacturing. The part can either be fixed on a temporary level so that the part last until the replacing part arrives or tear and wear parts can be used again after a small fixing. These options can be seen as a more ecological choice when parts can be re-used and costly breakdowns can be minimized if the broken parts can be repaired on a temporary basis.

Additive manufacturing is in the first place used by company 1 to counter planning errors and to make existing stocks more flexible. This means that stock keeping quantities can be lowered because if demand overlaps the existing stocks for some reason, the additive manufacturing machines can be used to manufacture parts to counter stockout situations. This in addition decreases inventory costs and lowers the amount of possibilities of stocked parts not being sold because of occurring obsolesce. The Company 1 is using a central warehousing strategy and all the additive manufacturing equipment is located into these central warehouses. By doing this company 1 decreases warehousing costs, but because of better awareness of demand patterns and shorter lead times when needed, they can gain almost the same benefits in a central warehousing strategy like in a decentral warehousing strategy. Additive manufacturing ensures more on time deliveries, better service towards customers and create more reliable and accurate supply chain management inside the company 1.

The machines are designed so that they do not require too complex training and due of this, costs of qualified employees are not high. The same operator can use multiple machines at the same time and this in combination to the raising wages globally makes it day by day more profitable to manufacture products locally with AM. Additive manufacturing can be used for the temporary fixing of broken parts and tear and wear parts, which provide new ways of customer service for the company 1. Because additive manufacturing machines have to run frequently to make the investments profitable and due of varying batch sizes, company 1 and stakeholders are lending production capacity inside their network. This can increase the production capacity if needed but it also requires close relations to the stakeholders inside the network.

The forecasting of spare part demand is still vital for company 1 because the main manufacturing methods are still the more traditional. Therefore, future demand needs to be calculated based on historical patterns to ensure sufficient stocks for occurring demand but by having as short inventories as possible. Compared to earlier years also the existing forecasting software has evolved which company 1 uses and it has more historical data at hand to make these more precise predictions on demand. Furthermore, additive manufacturing can be used as a backup if demand patterns are not accurate or intermittent demand occurs.

6.4.2 Scenario 2 – Products are designed to be manufactured with additive manufacturing

In the second scenario, trade restrictions and embargos are made between countries due of political conflicts and crises are affecting the whole world economy which is in turn affecting the machine and equipment manufacturing industry. Existing and potential customers are uncertain about future development and their investments in production equipment are decreasing. The trade restrictions between countries are shrinking sales of globally acting organizations and the share of domestic production is steadily increasing. These changes in the global political fields are affecting strategy choices of the organizations who offer manufacturing and processing equipment. Because the trade restrictions affect the global supply chains in a negative way, organizations have started to favor suppliers who are located closer to the global warehouses and the trade with them is not affected directly by the political conflicts. The usage of external suppliers located in countries with lower wages would still be possible, but because of uncertainty in global supply chains they are used only if the needed spare parts are nowhere else available.

Additive manufacturing technologies have developed to the level that the production of parts out of metal or plastic is profitable and has extremely good and solid quality. Other materials have still deficiencies and are manufactured with more traditional manufacturing methods. The production speed of the new additive manufacturing equipment is fast if the needed raw materials and manufacturing data is available. The prices of these manufacturing machines are decreasing which has decreased the raw material costs but in turn also increased new competition on the spare part markets. With additive manufacturing the production is slowly returning to domestic production and globally affecting trade restrictions are not affecting this way of producing the needed spare parts for company 2.

Piracy is seen as a problem for simple spare parts for the company 2. Copying technologies have evolved to the point that parts with uncomplex structures made out of a single material can be scanned and reproduced. The legislation has not been able to stop or decrease piracy and the quality of illegal reproduced spare parts is on a sufficient level for end customers. This has driven the company 2 to create more complex spare parts in structures for new designed equipment, which has been possible because of the change to use additive manufacturing technologies in spare part production. Old machines are still supplied with spare parts which are manufactured using subtractive manufacturing methods and they are sourced from suppliers because it is not profitable for the organization to change all designs of low profitable spare parts into additive manufacturing. The decrease in machine sales has forced the company 2 to design the machines in the way that they can be only produced with additive manufacturing and so that illegal reproduction is not profitable.

Attitudes towards the climate change as a phenomenon have affected also the manufacturing methods of the company 2. The responsibility of preventing climate change is seen as the manufacturers' responsibility on an individual level and these attitudes are affecting in addition the customers sourcing patterns. Additive manufacturing is seen as a competitive advantage for two reasons. First, customers favor more ecological manufacturing methods which the development of additive manufacturing has reached and second, more durable and lighter parts make the sold machines more energy efficient and are seen to challenge the climate change. Another way of facing competition has been, that the company 2 has started to sell up time of the machines and not just the physical spare parts. In this way the customer is paying for the uptime and the company 2 needs to ensure enough part and staff availability to maintain the vital uptime of sold machines.

The company 2 uses additive manufacturing only if spare parts are designed for additive manufacturing production but they have production capacity which equals the existing demand almost completely. If there are sometimes spikes in demand, the company 2 can use suppliers to cover the exceeding demand. One employee can run multiple additive machines at the same time and the technology is so automated that needed training and education for the usage of the machines is on a low level. The machines are located in warehouses which inventories are decreasing by time. There are still inventories for spare parts, which are for the old machines' but the amount is decreasing. One factor which is decreasing the old needed spare parts are the modernizations which are made to existing machines. In these modernizations the company 2 aims to change the old spare parts with new designed spare parts, which are suitable for additive manufacturing.

The company 2 uses a decentralized warehouse strategy, having warehouses in all continents. Each continent has few warehouses which each have different production equipment for different raw materials. These different production locations decrease costs of warehousing and sourcing different raw materials to each of them and the company has a team who is responsible for sourcing the needed raw materials and to supply it to the needed locations. Lead times are more accurate because needed spare parts can be manufactured faster without tooling costs and the production is not dependable on external suppliers. At this moment when traditionally fabricated spare parts co-exist, parts are still shipped in normal situations. If intermittent and urgent demand occurs, spare parts can be produced almost instantly inside the same continent to decrease delivery times and the durations of costly breakdowns. All so if trade barriers keep existing can the company still send the needed production data to those specific countries which cannot be reached with normal supply chains.

6.4.3 Scenario 3 – Suppliers are producing the needed spare parts with additive manufacturing

In the third scenario the overall global political state has been stable for a while without any global conflicts, which could have affected the manufacturing industry. The world economy is in an upswing phase and for this reason, the investment rate to new machines and manufacturing equipment has been increasing. There are no signs of changes in the near future for the existing political state and companies inside the manufacturing industry are thrusting that the demand for their products will steadily increase during the becoming years. Global supply chains are effective but because ethical factors are more important inside global networks, working conditions have increased on a global level and differences between production costs among countries have decreased. In general employees are more concerned about their health and noisy, dangerous and toxic working environments are declining in an exponential speed. Ethical production and a healthy working environment are not anymore seen as competitive advantages but as compulsory core attributes of every global acting manufacturing organization.

Automation in manufacturing is favored and the technical evolution of manufacturing technologies has led to the situation in which better working conditions are easily achieved without huge investments. Additive manufacturing is not the only technology, which has evolved during the years and manufacturers have to choose among different technologies, which can increase their overall profitability in the best way. The internet of things, big data and industrial robots are adapted increasingly into spare part manufacturing business and they are seen as promising as additive manufacturing by decreasing lead times, increasing the accuracy of deliveries and in better inventory management. The rapid evolution of all kind of technologies has pushed the legislation inside manufacturing and IP-rights forward on a global level and they are seen as strict and sufficient. This has increased the willingness to co-operate on a global level with suppliers and the external illegal competition has decreased during the years. Customers are not taking risks of using without permission manufactured spare parts, because these can affect their relationships to the original equipment manufacturers and they might even have to pay fines for using these illegal copies in their machines.

The technological evolution has also decreased emissions inside the manufacturing industry and climate change is not more seen as an actual topic. The manufacturing industry is changing towards a greener industry and more environmentally friendly manufacturing methods are already used in almost all production. The additive manufacturing has evolved to a level in which manufacturing of little spare parts with even small microcircuits is possible for reasonable prices. These electrical abilities, integrated already during the manufacturing phase, have made it possible to design even more complex parts which has in turn made it more difficult to copy existing product designs with existing scanning equipment. Assembling can be done in one manufacturing process and the only restricting criteria is still the camber size in the production. For this reason, all the sizable parts are still manufactured with traditional manufacturing methods.

The evident role of spare part suppliers has been growing to the company 3 during the decade because all of the manufacturing has been outsourced due to the company strategy and only assemblies of new sold equipment are done by the company 3. Even though assembling of small assemblies is possible with additive manufacturing, the company's sold products are so big that they still need additional assembling. The company has still central warehouses but because of better demand forecasting and stronger components they have been able to decrease inventory sizes and be more efficient in stock management. The money which have been earlier tied up into inventories and the management of it, is now used to convert existing data of spare parts to be suitable for additive manufacturing production. The overall demand has been decreasing due of more resistant spare parts, but their profits have been in turn gone higher. The demand for tear and wear parts has been growing alongside the growing equipment base and the forecasting of these spare parts follows predictable patterns, which are known more accurate because of the growing data base of historical demand. The company 3 has still legal obligations toward customers to serve them with spare parts for a specific time period and additive manufacturing was seen as a profitable solution for the obligations to supply rarely needed spare parts. They only need the 3D-data for the manufacturing of needed spare parts, which removed the need for costly inventories which company 3 had earlier for these rarely needed spare parts.

Sourcing of spare parts is done on two different levels now. The more traditional way uses still suppliers who produce spare parts with more traditional methods and this is way is used in most of the spare part cases because of the higher profitability. The second way is based on suppliers who use additive manufacturing techniques in their production. The company has in each of their sourcing category one of these firms who uses additive manufacturing and the supplier is capable to provide also the needed data conversion if needed. These AM suppliers are used if there appear urgencies in spare part demand and if components are needed which are not anymore in regular manufacturing. The company 3 do not have to stock these obsolete components by them self and only 3D-files are required. These materials can be delivered with short lead times, but they are more expensive compared to the first mentioned way of sourcing. A reason why this organization did not invest by themselves to this new manufacturing technology and equipment were the high prices of manufacturing equipment, the company's manufacturing strategy choices and because they want to focus on their core business and outsourcing manufacturing is seen as trustworthy and profitable.

7 CONCLUSIONS

This chapter will conclude the made findings base on theory and empirical findings. First are the theoretical findings presented following with the managerial implications. These include thoughts about the topic which business managers should take into consideration when planning and discussing about the possible benefits of additive manufacturing inside the spare part business. In the end of this chapter are the limitations of the research presented and future research topics suggested.

7.1 Theoretical findings and contribution

The aim of this study was to analyse the current state of spare parts management and how additive manufacturing might affect spare part business. The research provides possible scenarios based on the theoretical background and on an empirical research conducted to Finnish high-tech companies. This research topic was approached by formulating one research question and three sub-questions which will be answered in this chapter. A theoretical framework was constructed based on the literature review in the chapter 4.6. and this framework assisted in the creation of interview questions for the empirical part of this study. The literature review was constructed about three parts: Spare part management and the challenges, the current state of additive manufacturing technologies and a combination of spare parts management and what additive manufacturing might bring to it. In addition, this thesis includes a brief introduction to scenarios which were used in the analysis part to provide possible outcomes based on the made findings.

The theory of spare part management is presented on a general level and it aims to provide understanding on what academic publications have researched about spare part management and it also identifies common problems, choices and assumptions on the topic. The figure 1 of spare part management summarizes the found theory on spare part management and illustrates the topics about creation, fabrication, distribution and prediction of spare parts and choices related to them. These challenges were identified among the interviews, but efforts were already taken inside the interviewed organizations and spare part management is already done more efficient during the last years. A finding which was presented different in theory was the competition. It existed in all of the companies' spare part markets, but it was seen as acceptable, although for critical spare parts and for those more complex ones the companies did not recognized competition.

The second part of the literature review presented the resent finding about additive manufacturing on a general level and it identified the possible benefits and challenges of using this new evolving manufacturing technology. The third part of theory identified the possible changes which additive manufacturing might have on spare part business what it comes to production, supplying, other benefits and challenges of this evolving manufacturing method. The conducted interviews identified the same challenges what it comes to the adaption of additive manufacturing and saw the core benefits in the possibilities of additive manufacturing to decrease inventories, make lead times more accurate and to produce small quantities of needed parts almost instantly. One finding which was clearly identified based on the interviews but was not found during the literature review was the costly and resource draining converting of existing manufacturing data to be suitable for additive manufacturing. Another challenge which was not found in literature was seen in the needed testing of these new produced components and possible needed supporting activities for raw material sourcing and stocking, which all were assumed to create additional expenses.

Figure 3 in the chapter 6.4 illustrates the theoretical framework of this research and the theoretical contribution of this study. The framework shows the spare part process and what phases it contains. The Figure 1 shows more deeply this process and what choices have to be made during each of these phases. The figure 3 in addition presents the phases to which additive manufacturing might have an effect on and what external factors affect the adaptation of additive manufacturing to each of the phases. The theoretical framework identified that additive manufacturing might have an effect on the phases fabrication, distribution and prediction and these possible benefits were also identified in the conducted interviews. External factors in the technology itself were seen to be the main challenges which had to be challenged with the evolution of the technology and empirical findings supported the found challenges in the literature review. Additive manufacturing is seen as a possibility, but it has to develop further so that it could be integrated more into the existing manufacturing of the interviewed companies. The theoretical framework did not identified the phase creation as challenging for additive manufacturing, but the interviews showed that the creation phase is seen as a major challenge for the adaption of additive manufacturing in two ways: Spare parts are either not designed to be produced with additive manufacturing or because the needed manufacturing data for additive manufacturing is not available and the creation of the data would be costly.

The investigated topic has been evolving on an increasing speed but furthermore the role of spare part management has been improving during the years making the combination of both these topics a worthwhile research theme. The study's empirical part was conducted in Finnish high-tech firms with interviews which were formulated so that the afterwards presented sub-research question could gain also empirical findings. The original research question had three sub-questions which divided this research in to three parts. Each of these sub-questions will be discussed individually in this summary.

- What are the challenges in the spare parts management today?
- What improvements can additive manufacturing provide to manufacturing?

- What kind of scenarios can be seen for the combination of additive manufacturing and spare parts?

The first sub-question discussed challenges in spare part management today. Spare parts as components were not identified as the problem but everything what was happening around them had the possibility to create challenges. The importance of spare part documentation was raised as a vital part for possible success inside the spare part management. Stocks created in turn challenges in both ways: on one side if over stocked they caused additional expenses but on the other side stockouts of spare parts could result in expensive breakdowns at the customer. Another challenge was identified in the supply chain management of spare parts in which highly optimized supply chains can cause significant problems. Also, one of the characteristics of spare parts, intermittent demand was seen in theory and in real life as a challenge in today's spare part management.

The second sub-question focused on providing possible improvements which additive manufacturing could provide to manufacturing. It can be clearly seen that based on the interviews and partly on theory the most advances which additive manufacturing could provide are in the supply chains. Additive manufacturing was not seen as a substitute for more traditional manufacturing methods because it is still more expensive but is has the potential to change supply chains. Additive manufacturing can decrease stocks, remove shipping of products and it can increase component availability if the needed documentation is existing. Organizations have already started to research this new manufacturing method and they see also the benefits of this technology in decreased delivery times and more flexible stock management. AM manufactured parts can also have better attributes compared to parts which are manufactured with more traditional methods. Manufacturing can be made almost instantly; single pieces can be produced for the same costs as larger batches and manufacturing might be more ecological.

The third and final sub-question aims to provide scenarios on the combination of additive manufacturing and spare parts. Based on the found theory and empirical findings, three possible scenarios were composed and presented. Each of these scenarios were based on the assumption that additive manufacturing will continue to evolve and that it is at least at some level integrated to the spare part business. The first scenario used additive manufacturing as a flexibility in stock management increasing resource. It was not meant to produce all spare parts with additive manufacturing, but to use it to decrease stocks and aid in emergency situations. The second scenario spectated additive manufacturing from a whole different angle. The technology's adaption was seen to be most useful if it had been planned already in the actual design phase of the new equipment manufacturing so that those components in the machine were additive manufactured. This would decrease testing and transformation costs and provide instant spare part deliveries for these new equipment. The third scenario in turn focused on the suppliers. The company itself did not made investments to own production equipment but it had multiple additive manufacturing suppliers in each of their sourcing category. This provided the organization low transformation costs but more possibilities to acquire needed spare part faster if needed.

7.2 Managerial implications

The role of spare parts has changed during the years from a compulsory must towards a profit maker. On a general level spare parts are managed efficiently but there are still sectors which need to be improved. First of all, to ensure efficient spare part management it is important to have extensive documentation on the spare parts which are offered. If there is a demand for spare parts and the documentation is not on a sufficient level, it slows down the whole process. Documentation of new parts must be done in a way that it is still sufficient in the future. Documentation should be done about the actual features of spare part but in addition about the historical data about the demand of it. Based on the historical data it is plausible to predict future demand and act proactively for coming request from customers. Special software and known install base can provide usable information for strategic planning, but demand can be intermittent and, in these cases, the earlier mentioned right documentation is vital.

It was clear that the supply chain management of spare parts is vital to make the spare part business profitable and to ensure customers good after sales service. Spare parts in stock are seen as costly and therefore it is important keep them as short as possible but at the same time have stocks for critical spare parts. It can be difficult to decrease cost at of inventories and at the same time ensure sufficient availability for customers. With good stock management spare parts can be even more profitable. Fast delivery times are seen as a competitive advantage and even customers try to avoid stock cost resulting to even more demanding delivery schedules in which errors can be costly. Deciding between a centralized and decentralized strategy of stocking should be made case by case: A central strategy decreases costs and is easier to manage but in turn a decentralized approach serves the customers' needs more efficiently.

Competition is existing on the spare part market and at the moment it as seen as a small harm. To ensure that customers return to the equipment provider it is important to offer additional services for the spare parts which competition cannot imitate. Serving customers with spare parts is more than just supplying the components. Better spare part availability and short delivery times, responsibility on technical performance and maintenance services can be more important for the customer than lower prices which new competitors usually offers.

Additive manufacturing is evolving in an increasing speed right know and it has the ability to create components with whole new structures and features. It has been known for a while that additive manufactured parts can be lighter and even stronger compared to parts which are manufactured with more traditional methods. Raw material issues, quality of produced components surfaces and increased production prices are negative attributes which will most likely be resolved in the coming years. Additive manufacturing can produce complete assemblies in one production run and when mixing raw materials in the same production comes reality, produced components can have electrical circuits implemented already in the manufacturing phase and this creates new possibilities in the designs of products. Additive manufacturing can be seen as a more ecological choice if it can eliminate the shipping of manufactured products, but it is still unknown is the actual production process more ecological than subtractive methods because the energy consumption can be much higher. In turn additive manufacturing uses far less raw materials and the used energy can vary from ecological renewable sources to not so ecological energy production. Although the aspect of decreasing emissions from the transportation of finished goods can go to the transportation and fabrication of the needed raw materials for the production.

When it comes to additive manufacturing and the management of spare parts the most advantage compared to traditional manufacturing can be seen in the faster delivery times. If parts are well documented and they have the needed information for additive manufacturing they can be manufactured in any location and without any delays. Additive manufacturing does not add extra costs if designs are changed and the production quantities do not cause changes in the production prices. This manufacturing technology can be seen suitable for small batch productions and it can create flexibility to companies' stocks. In today's warehouses physical parts are costly to be kept in stock waiting for demand but in turn with additive manufacturing only the data for the component, production equipment and raw materials are needed. Additive manufacturing can now be seen suitable for parts which are made out of plastic and do not require testing from the selling company. It was identified that one obstacle for the adaption of additive manufacturing was the need for testing the produced parts and in addition the lack of suitable data for producing the needed parts.

Additive manufacturing will not replace more traditional manufacturing methods in the future when it comes to mass production but it can decrease production costs of smaller scale production. It can make supply chain management more efficient and provide more value to the customer. Additive manufacturing can be centralized which decreases labor and raw material costs and this could be suitable for a centralized warehousing strategy. If the warehousing strategy in turn is more decentralized is it possible to distribute additive manufacturing equipment in the same way closer to the customer which decreasing delivery times. Additive manufacturing provides possibilities but the transition to the usage of it will drain resources but it could make improvements for spare part availability and delivery times. Additive manufacturing should be integrated to warehouses to create flexibility in the stocking of materials. At this point additive manufacturing is not enough profitable to change all production to AM but it can be used to decrease inventory levels. This needs sufficient documentation which on spare parts and if it is at hand, inventory levels can be lowered for these certain spare parts. If the demand tops the actual stock, spare parts can be manufactured with AM as a safety measure. Another action which should be made is that future parts are designed to fit additive manufacturing. This ensures that the data is sufficient and testing is done already in the development phase. To summarize, at the development stage of additive manufacturing it should be integrated in combination with traditional manufacturing to create more flexibility to supply chains and new designed products should be designed so that they can be manufactured with additive manufacturing.

7.3 Limitations and future research

The theory behind this analysis was divided: About spare parts management there was just a limited amount of publications and they were all published years ago which raised the question if spare parts are managed so well nowadays that there is no need for further investigation or is there some other reason why it has not been a continuous topic in the academic research world. If more research is done about the same topic it is important to find more academic publications by using different collections of academic publications than in this thesis in addition. On the other hand, there was a lot of research conducted about this new manufacturing technology and how it could change manufacturing. It of course has a boom behind it at the moment but is was a surprise that so much was also researched about spare parts. To clarify, the research of AM and spare parts had usually the same researchers behind it and the focus was more in aviation, automotive and aerospace industries but the findings where easily transported to the other high-tech industries. Future research should focus to investigate publications around additive manufacturing in combination with spare parts in the high-tech industry.

A clear limitation of this research was that the topic was sensitive for the contacted firms. Only three of the contacted firms were willing to give an interview about the topic and two of them had to get think a moment if they were even allowed to talk about the topic. One company refused to take part of the suggested interview and those companies which did not responded to the interview request might have had a strict company policy not to provide any information on the theme. Although the count of the gained interviews was smaller than expected the gained empirical findings provided interesting opinions on the topic. If more research is conducted about the research question it is evident to get more interviews to form more comprehensive conclusions about the topic.

The future research on the topic will be interesting. The development and the investments which are made today can be seen on couple years from now. Like earlier analyzed, there might be a change in the becoming years what comes to some parts in the spare parts industry and it is curious to discover how it has affected the SCM and other logistical activities of companies who have changed from traditional manufacturing towards additive manufacturing. It is clear that in following years not all production will change but some tests and certain product families might be produced differently. Another research topic for the future is how additive manufacturing has changed other business sectors which have had no manufacturing earlier. Online stores are already providing some kind of 3D-printing but if the companies inside the logistics industry start losing market shares towards the digitalization of manufacturing, they might also evolve to something new. It should be noted that future research needs to have the most updated information to provide new insight in the rapidly evolving topic. The interviews showed that the transforming of data to be usable for additive manufacturing is a reason why there is so little additive manufacturing among the companies, which is a good finding to investigate further in future studies.

8 SUMMARY

The purpose of this conducted research was to explore how additive manufacturing might change the spare part business in the future. A literature review was conducted of the themes spare part management, additive manufacturing and the combination of these two topics. The literature review about spare part management helped in the construction of the figure 1 which illustrates the spare part process and figure 2 identifies the basic concept of the additive manufacturing process. The research was conducted as a qualitative research and the empirical findings were gathered with semi structured interviews among Finnish high-tech companies. The data was analyzed, and three different scenarios were created on possible outcomes of the mixture of additive manufacturing and spare part business for the year 2030. One uniting finding from the earlier published literature and the conducted interviews was the tough that additive manufacturing might in the first place affect the supply chain management of spare parts in the near future.

This research provides a theoretical framework which identifies the spare part process in general, external factors which affect in the adaptation of additive manufacturing into spare part business and what effects it can have on spare part management and the whole process. A short environmental analysis was made to provide needed background information for these scenarios and the basic idea of scenarios and how they were constructed was presented in the methodology part of this research. At the current state of this new manufacturing technology it is not seen to replace subtractive manufacturing methods but in recent years they can be used together to increase supply chain management in spare part business.

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APPENDIX

Interview questions

1. How are the spare parts manager or organized in your company?
2. Do you produce spare parts by your own or do you have outsourced the production?
3. How big is the volume of the spare part markets? Is there competition or obstacles on the market?
4. Are your spare parts categorised somehow and are there differences among them?
5. How do you manage critical spare parts?
6. How is the logistics of spare parts done in your company like inventory and supplying?
7. How good can you predict the demand of spare parts?
8. How does the selling of spare parts differ from regular products?
9. What can be seen as a challenge in the spare parts management?
10. What kind of competition is on the spare parts markets?
11. What kind of juridical responses do you have towards customers with spare parts?
12. How have the spare parts markets evolved recently?
13. Is additive manufacturing a possible choice in the future for your company and has it been considered or spoken about already?
14. What kind of possibilities and benefits do you see when comparing additive manufacturing to more traditional manufacturing techniques?
15. How easy would the transition to additive manufacturing be in your organisation?
16. What problems can be identified in additive manufacturing relating to products?
17. Are your companies' products suitable for additive manufacturing?
18. What kind of challenges IP-rights set regarding additive manufacturing?
19. How are products secured from external copying?
20. How do you see the development of subcontractors relating to additive manufacturing?

21. How can the digitalization of manufacturing affect logistics compare to traditional manufacturing?
22. Make to order vs. Inventories / Centralized vs. Decentralized,
23. Is the possible more ecological manufacturing method / supply an affecting factor when thinking to change to additive manufacturing?
24. Is it possible that customers start manufacturing the parts by them self and you start selling licences?
25. How do you see the effect of additive manufacturing to spare part sales?
26. Can the transmissions from traditional towards additive manufacturing be seen for some of your parts?
27. What are the threats for spare part sales if additive manufacturing is taken with a bigger share towards it?
28. What kind of products can be manufactured with additive manufacturing in the future?
29. Will you manufacture your products in the future or are they outsourced somewhere else where additive manufacturing is used?
30. How do you see your companies' inventories if spare parts could be manufactured according to existing demand?
31. Can additive manufacturing replace completely traditional manufacturing technologies?
32. Will the business model of spare part sales change in the future?
33. What kind of scenarios do you think could be predictable in the next ten years for your company regarding spare parts?

Coding structure

Spare part & Management	1, 2, 6, 9
Spare parts &Aftermarkets	3, 7, 10, 11, 12
Spare parts in general	4, 5, 8
Additive manufacturing & Spare parts	13, 14 17, 15
Challenges in spare parts	16, 18, 19
Additive manufacturing & Supply chain management	20, 21, 22
Disruption which additive manufacturing can cause	23, 24
Future orientated questions about the effect of additive manufacturing and spare part business	25, 26, 27, 28, 29, 30, 31, 32, 33

Person	message	finding	question	sub-category (a-h)