Business Model Innovation for Additive Manufacturing

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MASTER THESIS

Business Model Innovation for Additive Manufacturing

A case study of an established actor in the metal manufacturing industry

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Abstract

Metal additive manufacturing is a rapidly emerging technology, with a growing number of companies interested in its implementation. The technology can have several positive effects, such as more efficient production, reduced transports, more focus on circular economy and reduced costs. However, the manufacturing process is still relatively slow, where components require extensive post-processing and new knowledge in the companies involved. For a broad implementation, support functions need to be developed for, amongst others, selection processes, order handling, design, and post-processing.

To investigate possible uses for additive manufacturing, a case study was conducted at Alfa Laval. Their current conditions were mapped so that a new business model, specially designed for additive manufacturing, could be developed. Through interviews, future opportunities for the technology were identified, as well as problems related to these. Each possibility was examined related to how the company's external and internal processes would be affected and changes that could occur in the value chain. The business model blocks that would need to be innovated to support this development, while simultaneously contributing to UN's sustainable development goals, were discussed. Furthermore, these scenarios were evaluated on the basis of viability, feasibility, and desirability.

The report indicates that Alfa Laval should implement additive manufacturing for new products via R&D and for certain spare parts, and in line with this change, adjust their value creating processes, value proposition, and value capture. The two applications utilize different advantages of the technology, and which is best suited for Alfa Laval, and other manufacturing actors, needs to be evaluated during a longer test period within the business.

Keywords: metal additive manufacturing, metal 3D printing, industry 4.0, business model impact, business model innovation

Sammanfattning

Additiv tillverkning i metall är en teknologi under snabb utveckling, och allt fler företag intresserar sig i dess implementering. Teknologin har potential att leda till ett flertal positiva effekter, såsom mer effektiv produktion, minskade transporter, mer fokus på cirkulärekonomi och sänkta kostnader. Dock är tillverkningsprocessen fortfarande relativt långsam, där komponenter kräver omfattande efterbearbetning och ny kunskap behöver byggas upp hos involverade verksamheter. För en bred implementering av additiv tillverkning behövs också mer utvecklade stödfunktioner för bland annat urvalsprocesser, orderhantering, design och efterbearbetning.

För att undersöka möjliga användningsområden för additiv tillverkning genomfördes en fallstudie på Alfa Laval. Deras nuvarande förutsättningar kartlades för att en ny affärsmodell, särskilt utformad för additiv tillverkning, skulle kunna tas fram. Genom intervjuer identifierades framtida möjligheter för teknologin, samt problematik kopplad till dessa. Varje möjlighet undersöktes utifrån hur företagets externa och interna processer skulle påverkas av detta och vilka förändringar som skulle kunna ske i värdekedjan. De ingående delarna av affärsmodellen som skulle behöva innoveras för att stödja denna utveckling, och samtidigt bidra till hållbar utveckling i linje med FN:s hållbarhetsmål, diskuterades. Vidare utvärderades dessa scenarion utifrån ekonomisk och teknologisk genomförbarhet, önskvärdhet för kund, samt trolighet.

Rapporten visar att Alfa Laval bör implementera additiv tillverkning för nya produkter via R&D samt för vissa reservdelar, och i linje med detta förändra bland annat sina värdeskapande processer, sin värdeproposition, samt hur värde tillvaratas. Dessa två nischade användningsområden nyttjar olika fördelar hos tekniken, och vilket som lämpar sig bäst för Alfa Laval, och andra producerande aktörer, behöver utvärderas under en längre testperiod inom verksamheten.

Nyckelord: additiv metalltillverkning, 3D-skrivare, industri 4.0, affärsmodells-påverkan, affärsmodellsinnovation

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Calle Sandberg and Embla Tinglöv

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List of acronyms and abbreviations

AL	Alfa Laval
AM	additive manufacturing
BJ	binder jetting
BM	business model
BMC	Business Model Canvas
BMI	business model innovation
CM	conventional manufacturing
DC	distribution center
DED	direct energy deposition
DfAM	design for additive manufacturing
ERP	enterprise resource planning
IP	intellectual property
PBF	powder bed fusion
PLM	product lifecycle management
R&D	research and development
SDG	sustainable development goal
TTM	time-to-market
UN	United Nations

1 Introduction

In this section, theoretical background is provided for additive manufacturing, business models and business model innovation, along with an introduction of Alfa Laval and the thesis project.

1.1 Additive manufacturing

Additive manufacturing (AM), commonly referred to as 3D printing, has gained attention in public and within various industries in recent years. Along with technologies such as smart production systems, AM is an integral part of industry 4.0, the expected fourth industrial revolution (Nascimento et al, 2019). In AM, material is added layer by layer to make objects from digital 3D models, as opposed to conventional manufacturing (CM) methods where material is subtracted or molded. Various materials can be used for AM, including plastics, ceramics, and metals. (Bourell et al, 2017)

In comparison to conventional production methods, AM can facilitate customization of products, reduce lead times, and increase design freedom (Attaran, 2017). The method also has the potential of changing key production processes as well as the business model (BM) of companies (Petrick & Simpson, 2013). Furthermore, AM could contribute to sustainability and circular economy, as raw material waste can be reduced (Ngo et al, 2018) and supply chains are changed by more decentralized and digitalized production (Gebler, Schoot Uiterkamp & Visser, 2014). To ensure a future with less climate impact, the United Nations (UN) has set 17 sustainable development goals (SDGs); ranging from more sustainable production and consumption to lowered emissions of greenhouse gases (United Nations, 2021a). AM could contribute to several of these goals.

The drawbacks of AM fundamentally consist of high production costs, lack of available material, and long processing times (Mellor, Hao & Zhang, 2014; Ngo et al, 2018). Together, these factors contribute to limitations connected to mass production (Ngo et al, 2018). Additionally, there is a lack of standards regarding the technology because it is still emerging (Mellor, Hao & Zhang, 2014). There are also restrictions regarding size of the printed products, which pose constraints for a broader implementation (Attaran, 2017).

With these advantages and drawbacks at hand, there is a growing need to define when AM is an effective production method as well as which strategies to combine it with. This is especially important since technological advancement, without proper strategical development designed to capture business value, can fail to utilize the technology to its full potential. (Rayna & Striukova, 2016)

1.2 Business models & Business model innovation

There is no consensus in industry nor in academics regarding the exact definition of a business model, as stated by Ritter & Lettl (2018). It could be described as a holistic view of how firms conduct business (Zott, Amit & Massa, 2011) or how a firm connects their resources to their customers (DaSilva & Trkman, 2014). Although no complete definition exists, some key components of the business model are generally agreed upon; value creation, value capture, value proposition, value delivery and in recent literature also value communication (Rayna & Striukova, 2016). Several tools have been developed to concretize and simplify the usage of business models, for example the Business Model Canvas (BMC) by Osterwalder & Pigneur (2010) as well as more recent ones such as Rayna and Striukova's 360° Business Model Framework (2016).

Since companies are operating in an everchanging environment, there is a need to continuously develop business models to stay relevant and keep up with customer needs. To successfully implement new technologies into their businesses, companies must address the value aspects. This can be done by creating a suitable business model where the new technology is taken into consideration (Boffa & Maffei, 2019). By modifying key elements of the business model, and thereby changing its business logic, the firm can achieve business model innovation (BMI) (Ritter & Lettl, 2018). There is a large number of elements within business models, and each dimension can be discussed thoroughly when evaluating its impact. However, the connections between the elements are potentially even more important to consider during BMI, so that the general business idea remains coherent and aligned after changing the constituent components (Ritter, 2014). New technologies, such as additive manufacturing, have the potential of driving BMI and might even demand a shift in order for firms to stay profitable.

1.3 Alfa Laval

The thesis project is performed in cooperation with Alfa Laval (AL), a global manufacturing company with 39 production sites and representation in more than

100 countries. AL was established in 1883 and currently operates within three business divisions: Energy, Food & Water and Marine. Their key technologies are in heat transfer, separation, and fluid handling. With highly engineered products and strong local presence, AL has generated a large base of installed products and achieved global market leadership. (Gabrielson, 2021a)

With a focus on continuous innovation, AL aims to invest 2,5 % of their total net sales in research and development (R&D) annually (Alfa Laval, 2021a). In accordance with this strategy, a technology center has been built in Eskilstuna where AM is of high interest. For AL, this technology could become a driving factor for BMI, hence relevant knowledge on the area is coveted. They aim to develop an item selection process for AM, covering Capital Sales and Spare Parts delivery in AL. A vision is to implement AM as a core technology in Operations. (Gabrielson, 2021b)

This thesis project contributes to AL by providing them with suggestions on how AM could be integrated into the corporation's existing business model.

1.4 Problem identification

The objective of this master thesis is to understand the opportunities of AM within industrial production. In order to capture the potential value of AM, companies need to adapt their business models accordingly.

The following questions are addressed:

- How will the implementation of additive manufacturing affect internal and external processes, for companies in the metal manufacturing industry?
- How can a manufacturing company's business model be innovated to support an implementation of additive manufacturing?
- How can additive manufacturing be used to support the UN sustainability goals, specifically goal no. 9, no. 12, and no. 13?

These questions are answered by applying data on AM to the theory of business models and business model innovation, from literature and case studies. The conducted case study, where information is gathered from the industry, is related to AL. Additionally, this research question is specific for them:

- How can Alfa Laval benefit from the value adding aspects of additive manufacturing?

All questions in the thesis are initially answered for AL. Following an analysis of AM in this specific business context, learnings relevant to the general industry and academia are identified and structured. Finally, areas related to the results, where future research is needed, are mentioned.

Öberg, Shams and Asnafi (2018) identifies a number of missing perspectives in regard to research on AM. Among these, this report aims to contribute to research concerning potential value propositions, the role of manufacturing actors in the supply chain, and different revenue models that are possible to apply with AM.

1.5 Delimitations

This report is focused on the industrial use of metal additive manufacturing. Therefore, small-scale businesses and other materials used for AM are not included, unless explicitly mentioned. A limited amount of AM methods is covered, where those not of interest to AL are excluded from the thesis. Due to the Covid-19 pandemic there was no access to practical experience with AM, which could otherwise have been provided by both AL and LTH.

1.6 Structure of thesis

The structure of this thesis is presented in Table 1.1 below.

Table 1.1 Structure of thesis

Section	***Description***
1 Introduction	Background to the central subjects of the thesis; AM, BM, BMI, AL, and the research questions
2 Methodology	Description of the thesis process as well as the methods, and models, used in the different phases
3 Literature study	Results from the literature study; providing insights on AM, BM, and BMI
4 Case study	Results from the case study; providing general knowledge of AL and qualitative data from interviews with stakeholders at AL, AM experts, and other actors in the supply chain
5 Business model design	The development of a new BM for AL, using the 4I framework for business model design and the 360° business model framework to visualize the BM
6 Business model realization	The implementation of the new BM for AL, using the 4I framework for business model realization and the 360° business model framework to visualize the BM
7 Discussion	Evaluation and discussion of the thesis process and results, using selected quality dimensions and evaluation criteria
8 Conclusion & Implications	Presentation of conclusions from the thesis, covering the suggested BMI and answers to the research questions, as well as further implications

2 Methodology

The thesis process consisted of a literature study on additive manufacturing, business models and business model innovation, followed by a case study of Alfa Laval and business model innovation for an implementation of additive manufacturing. The methodology is described more thoroughly in this section.

2.1 Research process

During the project, an iterative approach was used to increase flexibility and reduce risks connected to traditional linear processes. This way of working is used in several fields of science, including design sciences and computer science: where the design process and agile development process ensures that the results correspond to the needs of important stakeholders – usually customers (Design Council, 2007; Abrar et al, 2019). Continuous contact with AL and the institution on LTH was maintained to reduce the risk of working towards results of little value to the company, and to ensure that it contributed to academic research. Feedback from these stakeholders was received and incorporated in all parts of the thesis process.

To ease planning and progress tracking, the double diamond model was chosen to provide some direction. This framework divided the process into four steps: discover, define, develop, and deliver (Design Council, 2007). The first two steps made up the first diamond, where relevant research was conducted, and the thesis questions were specified. The literature and case studies were performed in parallel, to enable project adjustments when supported by new insights. The last two steps made up the second diamond; the part of the process dedicated to generating and testing ideas to answer the thesis questions (Tschimmel, 2012). The model was applied to plan and follow the process, with an iterative approach supporting continuous movement between the stages. A simple visualization of the process is displayed in Figure 2.1.

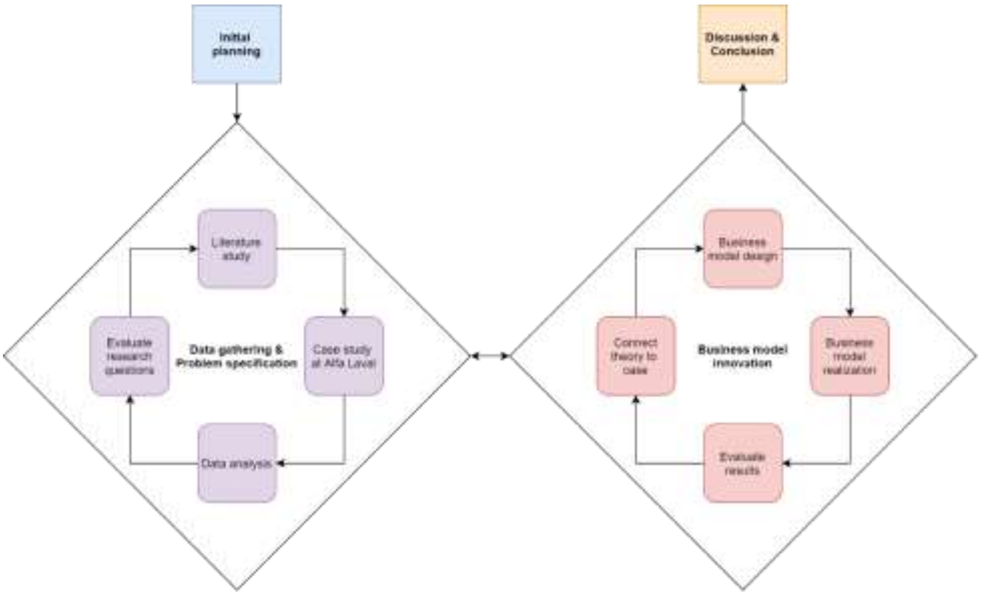

Figure 2.1 The thesis process, simplified, based on the double diamond principles by the Design Council (2007)

2.2 Literature study

To gather information and gain insights on the central subjects of the thesis, a literature study was conducted. The initial step was to collect large amounts of data regarding the subjects of the thesis, namely additive manufacturing, business models, business model innovation, and their interdependences. Subsequently, the data was narrowed down and scanned to develop the research questions and bring the project forward. It was performed somewhat exploratory, by first finding literature and then follow up on mentioned sources in that literature, in a continuous process. All literature was juxtaposed and reviewed to determine relevance and validity. When new areas of interest arose throughout the project, correlating literature was added to this collection. The literature search was conducted on LUBsearch and Google scholar; with search terms being various combinations of the following:

Metal additive manufacturing; implementing additive manufacturing; business models; business model innovation; business model impact; disruptive technology; circular economy; environmental impact.

In addition to the conducted literature search, representatives from Alfa Laval and LTH proposed relevant literature. In total, 113 literature sources were collected and reviewed, out of which 67 were referenced in the final report, see Table 2.1 below for further details.

Table 2.1 Structure of thesis

Subject	***No. of reviewed sources***	***No. of referenced sources***
Additive manufacturing	11	7
Business models	17	16
Business model innovation	15	13
Business impact by additive manufacturing	28	14
Sustainability and additive manufacturing	11	7
Implementation	9	6
Fabrication laboratories	4	0
Intellectual property	4	2
Spare parts	6	0
Item selection process	8	2
Total	**113**	**67**

2.3 Case study

To connect the theory to an industrial situation, a case study was conducted at Alfa Laval. The objective of the case study was to collect primary data on AL, including qualitative information on their current business model, organizational structure, and culture, as well as quantitative information on their AM operations and business as a whole. Additionally, an objective was to gain insight into the possibilities of AM in the general metal manufacturing industry. This data was collected during discussions and interviews with people within various business units of AL, AM experts with academic titles, and actors at different positions in AL's supply chain. A total of 17 interviews were conducted to gain deeper insight on these specific topics, as well as to get a broader perspective on how professionals view AM.

As a first step of the case study, information on the current situation of AL was gathered from annual reports and other public documents. Internal contacts were used to confirm information and provide complementing data, to generate a thorough picture of AL and their business model.

2.3.1 Interviews

Semi structured interviews were held for data gathering, to have a somewhat exploratory approach but still keep the interviews brief (Höst, Regnell & Runesson, 2006). These gave qualitative data on subjects such as AM, the business of AL, and their supply chain. People from various units of AL with different responsibilities were interviewed, to gain knowledge of not only the technological perspectives but also the organizational and economical perspectives. Other stakeholders, from AL's supply chain and the academia, were also interviewed to gather wider knowledge. The complete list of interviewees can be found in section 4.2, and a list of interview questions is displayed in Appendix B. Questions were added and adjusted along the way to support the iterative process, and constantly include new relevant findings.

2.4 Data analysis

The interviews were recorded to make it possible to later look through them and ensure that all relevant data was collected. All gathered information was also confirmed by the respondents to ensure that the interpretation of it was correct. In the analysis of the interviews, a systematic approach to qualitative research presented by Gioia, Corley, and Hamilton (2013) was used. The most significant of the respondents' answers were written down as ***first order concepts***. In this first stage of analysis, as it was important to not miss any information, the number of concepts was kept relatively high. In total, 161 first order concepts were collected. To narrow these down to a more manageable number, 37 ***second order themes*** were identified by connecting concepts that had similar implications. Subsequently, these themes could then be clustered together into 11 ***aggregate dimensions***, which represented the most important conclusions drawn from the interviews. The conducted interview analysis is presented in detail in Appendix A, where each Figure represents one aggregate dimension and shows the connections to their respective second order themes and first order concepts.

Since additive manufacturing can be seen as a breakthrough innovation, due to the various new application opportunities, traditional quantitative analysis methods were not sufficient for analysis and forecasting (Mohr, Sengupta & Slater, 2005). To support the qualitative analysis, individuals within AL and LTH who were either experts in AM, some in combination with business models, or had relevant knowledge of AL, were approached for comments and feedback throughout the thesis. This occurred especially during the business model development in section 5, the realization of the business model in section 6, and for the evaluation of results in section 7. It was also used as a basis for evaluating and validating progress and results.

2.5 Business model innovation for Alfa Laval

After conducting literature and case studies, the theory was applied to Alfa Laval to find out how they could utilize the possibilities of additive manufacturing. Abductive reasoning, a combination of deductive and inductive reasoning, was used to develop AL's suggested BMI for metal AM.

The objective with this thesis was to present a business model innovation for AM at AL. For this purpose, the 4I framework for BMI was applied on the case, where the four I's stand for initiation, ideation, integration, and implementation (Frankenberger, Weiblen, Csik & Gassmann, 2013). This framework was chosen due to its iterative nature, which aligns with the overall methodology of this report, as well as for its balanced number of constituent steps. In section 5, the first three steps were conducted. During the initiation phase, analysis was conducted to gather knowledge and to map the current situation, and business model, of AL. The ideation stage provided ideas of how AM could be incorporated into the company, and how they could benefit from it. During the integration phase, these ideas merged into one idea that was brought forward into a business model for AM. The final stage, implementation, was handled in section 6 and included the creation of a step-by-step plan for the implementation of the developed business model, as well as a supporting item selection process and a practical business case.

For the analysis of the current business model of Alfa Laval, as well as for the development of a new business model for AM, the 360° business model framework, by Rayna and Striukova (2016), was used. This model was chosen because it was familiar to relevant people at AL, in addition to being simple yet comprehensive and including core elements. The framework was developed specifically in relation to additive manufacturing. Other frameworks, such as the BMC by Osterwalder and Pigneur (2010), contain more aspects, although in the case at hand it was deemed exhaustive to map all these thoroughly. Additionally, the building blocks from the BMC and similar frameworks are generally covered in Rayna and Striukova's framework, although it provides more of an overview.

2.6 Validation

The *information* gathered during the literature study and the case study was validated by finding similar claims in other, reliable sources. Respondents of interviews were selected on recommendation and were asked questions related to their specific expertise. All data was reviewed critically, and the studies were intended to present as many perspectives as possible.

To simplify communication and ensure that different aspects of the suggested *BMI* were considered, some criteria were selected for evaluation. The developed scenarios for AM at AL were reviewed in regard to the following quality dimensions: feasibility, viability, desirability, and plausibility. Technological feasibility, economic viability, and desirability from the customer's point of view are all criteria in design thinking (Chasanidou, Gasparini & Lee, 2015). Plausibility is according to van de Ven (2007) a useful criterion when dealing with abductive reasoning and is evaluated with the aid of involved stakeholders. Van de Ven describes a conjecture as plausible "when it appears to be reasonable, believable, credible, or seemingly worthy of approval or acceptance". In section 7, the suggested BMI was evaluated and validated, both using literature and in discussion with involved stakeholders.

Additionally, three criteria were used to evaluate the legitimacy of the *report* in general: reliability, validity, and representability. The reliability of the data gathering and data analysis was evaluated in regard to random variations. The validity of the report was evaluated based on if the measurements had been carried out as intended. Finally, the representability was discussed, namely in relation to how generalizable the results were. (Höst, Regnell & Runesson, 2006)

3 Literature study

In this section, information gathered from the literature study on additive manufacturing, business models and business model innovation is structured and explained. Specific research on the impact of additive manufacturing on sustainability and business models is compared and compiled.

3.1 Additive manufacturing

There are numerous examples of AM being used in the industry, for example in biomedicine and aerospace (Ngo et al, 2018). The methods using metal are all generating the finished products using layer-by-layer techniques, usually with metal powder as raw material. However, there are technological differences that result in slightly niched uses for the respective methods of metal AM (Yang et al, 2017). Three of these are of importance to the thesis project, as they are being researched by AL, and will therefore be further explained in this section - along with a general description of the AM process.

3.1.1 General process

To create a product using AM, it must first be visualized and modeled using computer-aided design (CAD), as this information can easily be adjusted to a format supported by the printer (Yang et al, 2017). Before production, support structures are added to the design to ensure it will remain stable during production, and the CAD model is prepared by being split into 2D layers. During the production phase, each layer of the model is created and merged to the other layers, from the bottom up. Pictures of the separate 2D-layers can be taken, and analyzed, to ensure that eventual faults are detected during production (Öhlin, 2021). No unique tools, similar to casting molds, are required for AM (Holmström, Partanen, Tuomi & Walter, 2010). When the run is completed, post-processing is performed to enhance physical capabilities, remove support structures, and improve surface finish (Yang et al, 2017).

3.1.2 Methods of additive manufacturing

A common method for AM is powder bed fusion (PBF). With this method, the creation of a new layer begins by spreading metal powder over the previous layers. By using a laser or an electron beam as energy, the top 2D layer is melted or sintered to fuse with the others according to the digital file. Subsequently, this is done for each layer of the 3D model. Unused material is then recovered from the powder bed to be reused in future manufacturing. Though, material used for support structures cannot be recovered. Some post-processing is needed to ensure high quality of the product, for example regarding topology and solidity. (Yang et al, 2017)

Like PBF, binder jetting (BJ) uses a lowering platform to continuously connect the top 2D layer of a powder bed to the ones below. Instead of melting or sintering the metal at this stage however, a binder material is used to hold the powder in shape. The printed product resembles the intended 3D model, but several stages of post-processing are required. The first of these stages is a heating process to sinter the metal and remove binder material, resulting in a porous and brittle product – a green body. To increase density, the model can then be compressed or infiltrated with a metal that has a lower melting point. The finished component is somewhat smaller than the related green body. (Yang et al, 2017)

Direct energy deposition (DED) is a term used for several separate AM methods. Two of these are laser engineered net shaping (LENS) and electron beam freeform fabrication (EBF3). With LENS, metal powder is melted using a laser beam, whereas EBF3 uses a wire as raw material and an electron beam as energy. What unites the DED techniques is the procedure of material and energy being simultaneously deposited at the exact location where material is to be added to the model. Spot-by-spot, the layers are formed to finally complete a 3D product. The tools used for DED can usually move along multiple axis. (Yang et al, 2017)

Due to slight differences in the production processes, the separate methods are niched and can complement each other for a manufacturing unit. PBF and BJ can generate products of high quality with fine powder, while being relatively slow and expensive (Ngo et al, 2018). BJ requires more post-processing while PBF is more restricted regarding which metals are supported (Yang et al, 2017). DED is less accurate but quicker, more flexible and supports larger components. Due to the flexibility of the axis, it is also useful for reparations (Ngo et al, 2018). Different methods can therefore be selected depending on which factor is most critical: time, accuracy, material, or size. A comparison between the mentioned methods is presented in Table 3.1.

Table 3.1: Comparison between methods of additive manufacturing

Method	*Advantages*	*Disadvantages*
PBF	Higher quality	Supports fewer materials Slower
BJ	Higher quality	Requires more post-processing Slower
DED	Supports larger components More flexible Quicker	Lower quality

3.1.3 Advantages and disadvantages

Apart from their specific characteristics, the different methods of additive manufacturing share some general advantages and disadvantages in an industrial context. Compared to CM methods, see Table 3.2, AM increases design freedom; which can reduce waste of raw material, increase design complexity, and improve product functionality. The method is suitable for manufacturing in small batches and for mass customization (Ngo et al, 2018; Holmström, Partanen, Tuomi & Walter, 2010). These benefits are consequences of the high recoverability of unused raw material and the lack of need for premade molds and similar tooling (Holmström, Partanen, Tuomi & Walter, 2010). The time-to-market (TTM) for new innovations is also shortened by AM, as is the lead time for customized products (Attaran, 2017).

However, despite these advantages, the method is not perfected in its current state. Technological progress is needed to increase the properties of AM, for example considering production time, accuracy and automatability (Attaran, 2017). The selection of metals is small, and machines and powders are expensive. Additionally, digital systems to support the production are yet to be optimized (Ngo et al, 2018). Another issue with AM is that it requires much post-processing of parts, contributing to a longer production time, as the production method does not print finished products. Post-processes such as heat treatment and removal of support material are therefore needed, to different extents, depending on which method of AM is used (Mellor, Hao & Zhang, 2014).

Table 3.2: Comparison between conventional manufacturing and additive manufacturing

Attribute	*Conventional manufacturing*	*Additive manufacturing*
Component size	Small-large	Small
Customizability	Low	High
Design freedom	Low-medium	High*
Material selection	Large	Small
Need for molds and tools	High	Low
Post-processing needs	Low	Medium-high
Preferred batch volume	Large	Small
Production speed	Slow-fast	Slow
TTM	Medium	Short

*this can result in higher functionality, more complex designs, and reduced usage of raw material

Furthermore, AM supports a future of more decentralized manufacturing, which could reduce carbon emissions due to lesser needs for transportation (Gebler, Schoot Uiterkamp & Visser, 2014; Attaran, 2017). Another opportunity may be to utilize software for design optimization; to edit design and topology, generate support material, and enhance internal structures (Gardan & Schneider, 2015). This would change the role of the designer, by providing them with tools to generate designs directly from problem statements. Lots of alternatives could be created, and tested in simulations, to ensure optimal functionality even before the production phase is initialized (Kayser & Penna, 2020). AM also creates an opportunity to establish digital databases of 3D-files that relate to different products, which could end up decreasing the traditional need of physical storage if combined with on-demand manufacturing (Zhang, Jedeck, Yang & Bai, 2019). This opportunity can be referred to as digital warehousing (Gabrielson, 2021b).

Even though the opportunities of AM are many, there are currently barriers holding it back from becoming an established manufacturing method (Öberg & Shams, 2021). Small firms lack financial resources and are dependent on larger firms adopting the technique, in order to secure supply chains. For industrial manufacturers, AM must first become management priority where the new process can be clarified, and even then, the problem of having it accepted within the organization remains (ibid). Mellor, Hao, and Zhang (2014) mention similar difficulties for a rapid prototyping company moving their AM business into rapid manufacturing; process complexity, immature supply chains and resistant internal culture could all become barriers to overcome. With the spread of additive manufacturing, there are also rising concerns regarding the protection of intellectual property (IP). AM enables counterfeiting items, for example if licensed items are scanned and printed by other actors, which raises questions regarding who owns design and geometry (Kurfess & Cass, 2014). There are still unanswered questions under current patent laws regarding how to handle third party repairs, and new strategies related to IP may be needed in order to navigate in the AM landscape (Ballardini, Flores Ituarte & Pei, 2018). This immaturity of the technology also shows in the lack of available AM standards (Mellor, Hao & Zhang, 2014).

Table 3.3: SWOT-analysis

Strengths	***Weaknesses***
Design freedom	Slow production speed
High customizability	Limited scalability
Short TTM	Size restrictions
No need for molds and tools	Post-processing needs
	High costs
Opportunities	***Threats***
Digital warehouse	Intellectual property
Print-on-demand	Supply chain immaturity
Globally distributed manufacturing	Internal resistance
Mass customization	Lack of standards
Manufacturing simulations	Few materials available
Design optimization	

In Table 3.3, a SWOT analysis is presented, as to map the strengths, weaknesses, opportunities, and threats of the technology of additive manufacturing. The most prominent strengths are the design freedom and the customizability that the technology enables (Attaran, 2017; Niaki & Nonino, 2017). The weaknesses, however, are related to size restrictions and slow production speed (Attaran, 2017), as well as the limited scalability and need for post-processing (Ngo et al, 2018; Mellor, Hao & Zhang, 2014). Using AM might enable globally distributed manufacturing (Bogers, Hadar, & Bilberg, 2016), as well as mass customization (Ngo et al, 2018). Software could run simulations to optimize design and increase product functionality (Kayser & Penna, 2020), while digital warehouses could create a shift from producing batches in advance and storing them in physical warehouses, to instead using AM to manufacture on-demand (Zhang, Jedeck, Yang & Bai, 2019; Despeisse et al, 2017). However, these digital solutions may lead to issues regarding protection of IP (Kurfess & Cass, 2014).

3.1.4 Items suitable for additive manufacturing

When discussing AM suitability, there are physical restrictions in terms of technological feasibility and mechanical properties, such as restrictions in size, material, and structure (Attaran, 2017). Additionally, as AM still imposes high costs (Mellor, Hao & Zhang, 2014; Ngo et al, 2018), there is a need to generate substantial revenue or achieve cost savings for it to be economically viable. As AM enables mass customization, highly customized items may be preferred as printing candidates, in addition to more standardized parts produced in small batches (Attaran, 2017).

When implementing AM in a business, the affected products can be divided into those demanding major design changes and those only needing minor design changes. Major design changes could for example be used to improve product capabilities, while minor design changes are more suitable when wanting to retain a traditionally manufactured product but change the production method to AM – to improve the process. With each category, there is a different set of value adding aspects and difficulties. The process of identifying components for minor design changes could be mostly automated, as it generally considers quantifiable data. For components demanding major design changes there needs to be skilled engineers involved, since the identification process is usually based on more complex criteria that utilize different aspects of the possible design improvements. (Klahn, Fontana, Leutnecker & Meboldt, 2020)

By using data from Enterprise Resource Planning (ERP), Manufacturing Operations Management (MOM), and Product Lifecycle Management (PLM), technical and economic criteria can be more easily assessed; contributing to the selection of parts to produce using AM. (Klahn, Fontana, Leutnecker & Meboldt, 2020)

3.2 Business models

A firm's business model is one of the central parts in the success of a business; two commercializations of the same technology might yield radically different economic outcome, depending on the business models employed (Chesbrough, 2010). Although industry representatives and scholars agree that business models are an emerging field of analysis (Li, 2020; Boffa & Maffei, 2019), there is no consensus on a general definition (Ritter & Lettl, 2018). In the context of manufacturing industries, there is not yet a lot of research on the contribution of business models (Boffa & Maffei, 2019). This section aims to conceptualize the essence of business models, describe their inherent logic, as well as provide some examples of what they may look like.

3.2.1 Frameworks and tools

In the early 2000s, after the internet boom had made *business model* a popular term, it became closely connected to digital businesses (Magretta, 2002). In those days, business models were generally viewed as logical tools to help firms make strategic decisions, or as stories describing how firms work (Andreini & Bettinelli, 2017). Chesbrough and Rosenbloom (2002) saw them as an illustration of a firm's strategy, while others saw them as tools for designing the organizational functioning (Zott & Amit, 2010). More recently, academics focus more on the value aspect, specifically either value creation or value capture (Li, 2020). Andreini and Bettinelli (2017) claim that a parallel shift has occurred, from focusing on the strategic aspects into becoming a more cognitive framework. They also draw the conclusion that many scholars claim to be in the mainstream of what a business model is, even though they have different interpretations.

According to Ritter and Lettl (2018) there are five different ways of interpreting business models: as archetypes, alignments, activities, logics, and elements. This ambiguity also translates to how business models relate to surrounding research, where they are not instantly applicable but work as common ground for discussions of different theories (ibid). Although no clear definition exists (Andreini and Bettinelli, 2017), a large number of frameworks aim to describe and conceptualize business models, practically applying *why* and *how* business takes place.

Osterwalder and Pigneur (2010) have developed the BMC, containing nine building blocks with value proposition in focus; while also taking business infrastructure, customers and financial streams into account. This framework has been widely used in education and industry alike since its introduction, although it has been criticized for its lack of focus on value, which is only explicitly stated in one of its nine building blocks (Li, 2020).

IBM has instead used a more comprehensive approach with their Component Business Model, that aims to visualize the underlying processes in a concrete way while enabling firms to experiment with various business models (Chesbrough, 2010). This goes in line with research by Flammini, Arcese, Lucchetti, and Mortara (2017), which advocates that multiple business models can coexist within a company and that business model design and reconfiguration should be conducted simultaneously. The Component Business Model maps a large number of components and aims to allocate the importance of each, although there has been criticism against the model in terms of the accuracy of this allocation (Shivade, Mukri, Ramnath & Ramanathan, 2011).

On the other side of the spectrum, Rayna and Striukova (2016) offers a smaller framework called the 360° Business Model Framework, with just five components: value proposition, value capture, value delivery, value creation, and value communication. It builds upon roughly the same aspects of business as the BMC, although presents information in a less detailed manner by offering an overview of the core processes. Similarly, Li (2020) has developed the Holistic Business Model Framework. This includes for example value proposition and value architecture, while also bringing evaluation of the business model in terms of stakeholder credibility and financial sustainability, into the picture. Related to how the framework has been developed, Li (2020) defined a business model as "a firm's rationale and logic for value sensing, creation, distribution and capture". Compared to other frameworks, these two are more concise, while focusing on the value aspects of businesses. However, they are less comprehensive than other models and may not cover all aspects of interest. Both frameworks were created as results of literature studies on business models, to structure and strengthen elements according to their reoccurrence (Rayna & Striukova, 2016; Li, 2020).

More recently, scholars have suggested a deeper focus on sustainability, integrated at the core of the business model (Evans et al, 2017; Stappmans, 2015). Joyce and Paquin (2016) have built upon the BMC and added two layers to the existing economic one; a social layer and an environmental layer. This is called the triple-layered BMC. The demand for vertical coherence (between the layers) is highlighted on top of the horizontal (within the layers) as all three of them are designed to complement the others. Adding two layers to the already comprehensive BMC creates an even more detailed framework. As of yet, the triple-layered BMC has only been applied to manufacturing companies by a limited number of scholars (García-Muiña, Medina-Salgado, Ferrari & Cucchi, 2020).

Table 3.4: Comparison of business model frameworks

Framework	***Advantages***	***Disadvantages***
Business Model Canvas	Well established Comprehensive	Does not have value at its core
IBM Component Business Model	Comprehensive Practical aspects	Too detailed
360° Business Model Framework	Value aspects at its core Concise	Does not cover all aspects of business
Holistic Business Model Framework	Value aspects at its core Includes evaluation of BM	Does not cover all aspects of business
Triple-layered Business Model Canvas	Includes sustainability Comprehensive	Does not have value at its core Too detailed

The advantages and disadvantages of the various frameworks are presented in Table 3.4. They differ somewhat in wording and execution, though they all aim to provide practical tools for describing, analyzing, and developing business models. According to Zott, Amit & Massa (2011), despite the different approaches used in conceptualization, they all have the value creation and value capture elements in common, as well as the emphasis on a holistic view of business.

3.2.2 Business model archetypes

When discussing business models, it is useful to look at *archetypes* that describe the most common ones. They explain the way a firm is doing business, by looking at their value creation process and revenue streams (Ritter & Lettl, 2018; Taran, Boer & Lindgren, 2015). Archetypes present examples of common applications of business models in the industry and can be used complimentary to the frameworks.

Cabage & Zhang (2013) have developed *The 7 Fundamental Business Model Personalities*, consisting of three primary business model archetypes: product, service, and trade. Perhaps the most intuitive one relates to products, which describes a company that manufactures one or several products and earns revenue from selling these for one-time costs. Similarly, the service archetype is when a company sells a service and charges a fee. The third primary archetype is trade, where the firm connects buyers and sellers, and the revenue stems derive from procuring items to a lower price than what the firm sells them for. By combining these three, the authors generate the three secondary archetypes of marketplace, brokerage and subscription, and the tertiary archetype ecosystem. (Cabage & Zhang, 2013)

The archetypes mentioned above can be applied in numerous ways with variations of target customer segments, customer relations and so on. As an example, solely the marketplace as a business model has several potential revenue streams and cost structures connected to it. Täuschen and Lautien (2018) have studied the emergence of marketplaces and discusses the impact companies have with these kinds of business models, and present Uber and Airbnb as examples. In general, the emergence of internet and digital tools have led to a number of new business models being developed to help capture value from new forums (Li, 2020). For example, one well used archetype amongst digital companies is the freemium model; where businesses offer a limited version of their product free of charge, while they provide the entire product for a certain cost (Kumar, 2014). Companies such as LinkedIn, Spotify, and Dropbox are using this model.

Business models are well-used by the industry, although not universally defined. However, there are countless frameworks that aim to describe what a business model is and how to design and reconfigure it, as well as archetypes that describe different ways firms are acting on the market. In summation, a business model is about why and how a firm conducts business: where value proposition, value creation, and value capture are central aspects.

3.3 Business model innovation

In a changing world, it is essential for firms to continuously sense new needs and emerging trends in order to stay relevant to their customers (Zott, Amit & Massa, 2011). Companies that have successful business models might still fail when new technologies are introduced (Cavalcante, 2013). Oftentimes, it is not simply the technology in itself that stands for innovation, but the novel application of it in various contexts (Adner & Levinthal, 2002). Thus, companies' business models must be updated, more or less continuously. BMI is therefore necessary to create and capture value, and there is wide consensus considering its importance to the success of a firm (Zott, Amit & Massa, 2011).

3.3.1 Frameworks and tools

As there is little consensus regarding the definition of business models, there are many different descriptions of BMI (Cavalcante, 2013). The added complexity for non-static frameworks, compared to business models, makes consensus regarding BMI even weaker (Ritter & Lettl, 2018). Andreini & Bettinelli (2017) have conducted a systematic literature study that aims to clarify the view of BMI. Generally, according to their findings, BMI is about managing ways of creating and capturing value from customers and other stakeholders, through organizational restructuring or various adjustments of a firm's relations to partners, suppliers, and customers.

Just as there are frameworks to describe business models, there are tools that aim to describe and facilitate the process of BMI. One example of a framework used to generate BMI is the Cambridge Business Model Innovation Process, consisting of three subprocesses: concept design, detail design, and implementation (Geissdoerfer, Savaget & Evans, 2017). Each of these subprocess include defined activities, such as ideation, prototyping, and experimenting. Another model is the 4I-framework for BMI, which consists of initiation, ideation, integration, and implementation (Frankenberger, Weiblen, Csik & Gassmann, 2013). This is an iterative model where the different steps may be revisited during the innovation process, as opposed to the Cambridge BMI Process that is linear. The Cambridge process is more thorough than the 4I framework, while the 4I framework focuses more on the central aspects and activities performed during BMI. A comparison of these frameworks is presented below in Table 3.5.

Table 3.5: Comparison of Business Model Innovation Frameworks

Framework	*Advantages*	*Disadvantages*
Cambridge Business Model Innovation Process	Comprehensive Detailed	Complicated
4I Framework	Clear focus Iterative	Does not cover all steps

Taran, Boer and Lindberg (2015) claim that any change within a company can be considered as BMI. However, they use three criteria to determine and describe the innovativeness of these changes: radicality, complexity and reach. Radicality concerns how much the respective business model building blocks are changing with the innovation, while complexity refers to the number of affected building blocks. Reach describes the context in which the BMI adds something new, ranging from limited to the company, to the industry, or to the world (ibid).

From another point of view, Casadesus-Masanell and Zhu (2013) offer a framework of three different steps, describing how a new market entrant may choose its business model and how an incumbent firm can react to this. The first step is when the innovative entrant chooses between competing with the incumbent firm's traditional business model and finding a more innovative one. The next step is the incumbent firm's strategic decision on their counter move, depending on how the entrant acts. The third step is about monetization, namely how successful the firms' business models are on the market.

More generally, business model innovation is often divided into two separate processes: business model design and business model reconfiguration or development (Massa & Tucci, 2013; Cortimiglia, Ghezzi & Frank, 2016). As mentioned earlier, Flammini, Arcese, Lucchetti, and Mortara (2017) argue that since several business models can coexist within a company, business model design and business model reconfiguration can and should be continuous processes that are run in parallel, to keep up in the everchanging environment.

3.3.2 Utilizing business model innovation

One of the most important aspects when creating and making decisions concerning business models is to identify and meet customer needs, and to later capture value from this process. How this is done is largely decided by a firm's dynamic capabilities, both in regard to their ability to sense new opportunities and the ease of reorganizing the firm (Teece, 2018). When working with BMI, it is crucial to have deep understanding of the firm's capabilities as well as competing firms' strategies and abilities. Business model design is strongly connected to the firm's dynamic capabilities; in order to know which skills to develop, they need to sense value opportunities to pursue (Teece, 2010). The importance of sensing and seizing potential value is something that also business leaders in Li's (2020) case studies agreed upon.

Among business leaders and academic scholars, there is generally consensus that product innovation has to rely on several support activities in most cases, in order to be successful (Zott & Amit, 2010; Visnjic, Wiengarten & Neely, 2016). Aligning the innovativeness of the BMI, both with the openness of the innovation and the strategy of the company, is recommended for decision making on innovation (Taran, Boer & Lindberg, 2015). This is supported further by Taran, Goduscheit and Boer (2019), along with a conclusion that the risks associated with BMI seem to be dependent on this fit, and how complex the innovation is. The involved risk of BMI can however be decreased by initially implementing the changes in parallel to the existing business, to evaluate the solution and later decide upon which business model to continue with (Bucherer, Eisert & Gassmann, 2012).

An example of the usefulness of BMI is given by a case study on Xerox printing machines, performed by Chesbrough and Rosenbloom (2002). The conclusion is that novel technologies, that traditional business models cannot generate value from, might be highly successful when combined with a suitable business model (ibid). Alas, managerial decisions are highly relevant to the success of firms, and developing and updating business models is crucial in this context.

3.3.3 Trends

Li (2020) points out that the past decades have been dominated by business model innovation in response to the digital transformation, e.g., companies implementing new technology in order to better create and capture value. In many cases, this does not represent a radically new business model, but rather an addition of digital resources into the existing business model. Entirely new business models are sometimes enabled though, for example by a technological innovation that radically changes the landscape (Teece, 2018). In recent years, many manufacturers have made a shift from simply offering a product to also providing services, to attract customers when product differentiation is difficult to achieve (Yang & Evans, 2019).

Lately, as in many aspects of society, sustainability has gained attention, and its effect on BMI has been investigated from various perspectives (Evans et al, 2017; Stappmanns, 2015). Business model innovation has been described as a potential way to integrate sustainability into businesses (Schaltegger, Lüdeke-Freund & Hansen, 2012). Additionally, a firm's profitability may benefit from a deeper focus on sustainability (ibid).

In summation, BMI has experienced a surge amongst researchers, and is generally viewed as necessary for firms to become and to stay successful. There are frameworks that illustrate processes that firms can follow when designing and implementing new business models. However, the effects of BMI are usually very far reaching, within the company as well as to various stakeholders and networks, which can make firms hesitant to implement new business models (Evans et al, 2017). Regardless, companies inevitably need to react to changes in their environment, such as technological advancements or new entrants, and may be able to profit from successfully utilizing BMI.

3.4 Business model impact of additive manufacturing

It has been established that new technologies can have large impact on firms' strategies and business models, often leading to, or in some cases demanding, business model innovation (Cavalcante, 2013; Chesbrough & Rosenbloom, 2002). The emerging technology of additive manufacturing is no exception. AM impacts both internal processes and external relationships with suppliers and customers. For example, the shift towards AM changes the internal competences needed as a lot of focus is put on design and software skills, and the core activities that the company conducts might have to be adapted accordingly (Simpson, Williams, & Hripko, 2017). At the same time, the bigger picture will be changed as supply chains are disrupted, and new roles and positions are presented. Additionally, AM holds great potential regarding the sustainability of firms and value chains, reducing the climate footprint and decreasing environmental damage.

3.4.1 Impact on individual firms and supply chains

For firms that choose to adopt AM, there is a possibility that their operations and internal processes are widely affected, as the needed workforce knowledge will shift towards the new technology and its application (Simpson, Williams, & Hripko, 2017). For example, industrial workers must be able to optimize the topology of the products', in order to secure high quality (Gardan & Schneider, 2015). There is also a need for companies to acquire and maintain software, to support data analysis and algorithms for design and manufacturing of products (Zhao & Rosen, 2017). Thus, several components of the business model might have to be adapted in the case of AM implementation (Öberg, Shams, & Asnafi, 2018).

AM also creates opportunities to move production closer to end users, and shorten lead times, as products may be printed on-demand (Oettmeier & Hofman, 2017). As TTM is shortened and products become increasingly complex and innovative, the business model is bound to be changed at the core. AM not only supports process innovation, but paves way for product innovation, which creates possibilities for market expansion (Niaki & Nonino, 2017). Selling new products to new markets could significantly alter the value proposition of a firm. Christopher and Ryals (2014) argue that AM combined with the usage of big data may transform what is today called a supply chain into more of a demand chain. As products can be printed on demand, manufacturers can decrease the number of warehouses and wait for orders from customers before initiating production. This creates new possibilities in terms of firms' core value, for example by going from mainly offering products into putting more and more emphasis on the service aspect (Despeisse et al, 2017). An example of this type of shift is an effort by Rolls Royce to extend their product offering into a further reaching service, by letting customers pay per fly hours for the engines and offering a variety of add-ons. The core elements of their value propositions changes from simply an engine into a service offering with integration and reliability improvements (Christopher & Ryals, 2014). This way, the company establishes a close relationship with their customers. Likewise, AM could increase direct contact between consumers and producers and, by providing a high value product, create an incentive to use a product-service business model (Despeisse et al, 2017).

The value chain of AM could also, generally, be shorter than that of CM. While conventional companies usually receive material and components from a large network of suppliers, AM could decrease the number of needed components, and thereby suppliers, as the most crucial supply would be metal powder (Oettmeier & Hofman, 2017). One example of this is the Ariane project, when a European joint venture used AM to produce an injection head for an engine, decreasing the 248 constituent components into only one (Meyer, Glas & Eßig, 2020). The ability to react to such changes in the supply chain differs between smaller and larger firms; where larger firms may have an advantage due to their ability to invest in equipment and skilled personnel (Niaki & Nonino, 2017).

It is probable that different actors would be affected by the emergence of AM in different ways and to varying degrees. Depending on their position in the value chain, firms may need to take different actions to secure their success in an industry where AM is present. Findings from Öberg and Shams' (2019) case study, which involved a sub-supplier, a manufacturing firm, and a logistics firm, showed that all three were attempting to defend their own position while also chasing the role of the manufacturer, in response to the rise of AM. The actors took the threat of an emerging technology seriously and acted to fulfill new customer needs, although they did not consider how the others would respond. This moved the former partnering firms into competitors. In this case, AM seemed to disconnect firms' positions from their traditional roles (Öberg & Shams, 2019). There are numerous scenarios for how future supply chains for AM may look, where the extremes are being very centralized or localized (Li, Jia, Cheng & Hu, 2017). Either way, it is crucial for companies to analyze the actions taken by surrounding actors when deciding which strategy to follow (Öberg, 2019).

3.4.2 Impact on the general market

A literature study conducted by Savolainen & Collan (2020) suggests that there are four directions that business models for AM could take as the technology emerges; open incremental, closed incremental, open disruptive, and closed disruptive. According to their research, AM will either have a disruptive effect on the market, leading to radical BMI and a major change in the supply chain system, or be an incremental technology that works as a compliment to other production systems, which would not drastically change the way companies interact or are organized. In response to these scenarios, firms can choose to have mainly open business models, utilizing and contributing to open innovation and shared knowledge, or mainly closed, focusing on internally developed innovations and IP protection. Evaluating these directions in relation to the complexity of the innovation, may be important for decision making regarding the implementation of AM (Taran, Boer & Lindberg, 2015).

Since Savolainen and Collan's (2020) article concerns AM in general, including different materials and markets, the various scenarios might coexist in the future. For example, as Sandström (2016) points out regarding plastics, 3D printing has already been incrementally implemented in the hearing aid industry, completely taken over conventional production methods while not changing the industry leaders. On the other side of the spectrum there has been an increased level of home production using simple 3D printers, which has resulted in radical impact on concerned industries (Rayna & Striukova, 2016). Which path the metal AM market follows remains to be seen.

3.4.3 Impact on sustainability

As stated in section 3.1, AM has potential to change the manufacturing industry from its core, by enabling more resource efficient and quicker production processes for niched products (Despeisse & Ford, 2015; Nascimento et al, 2019). On a larger perspective, logistic operations could be drastically diminished if products were made on demand, near the customer, instead of being assembled by a large number of components from various locations (Öberg & Shams, 2019). Instead of mass producing and storing products, printing-on-demand could be realized with AM, which would lead to less waste of both raw material and finished products. Less complex product assemblies could also lead to improved recyclability (Despeisse et al, 2017).

The United Nations have developed an agenda for sustainable development, which includes 17 goals regarding various aspects of sustainability. Out of these sustainable development goals, AM has potential to substantially impact three:

- Industry, innovation, and infrastructure (SDG no. 9)
- Responsible consumption and production (SDG no. 12)
- Climate action (SDG no. 13)

Goal number 9 for sustainable development is to "build resilient infrastructure, promote inclusive and sustainable industrialization and foster innovation" (United Nations, 2021b). In many cases, AM can simplify the supply chain of products and use on-demand production, reducing the amount of discarded goods (Machado, Despeisse, Winroth, & da Silva, 2019). Instead of mass-producing items, storing them, and sending them across the world, companies could wait for orders from customers before starting production. AM constitutes process innovation, and paves way for thorough product innovation, thereby contributing to the innovation aspect of the goal (Niaki & Nonino, 2017).

The SDG number 12 is to "ensure sustainable consumption and production patterns" (United Nations, 2021c). AM could largely impact the energy consumption in production, which would increase sustainability in more than one way; by contributing to resource efficiency as well as reducing emissions caused by fossil fuel usage (Despeisse & Ford, 2015). It is also possible that AM will lead to products being redesigned to have higher quality and better sustainability. Higher quality on spare sparts could also contribute to prolonged life for machines, although this might lead to energy inefficient equipment staying in use for longer, which would have a negative impact on the climate. Nascimento et al (2019) points out that if waste material is to be reused in production, AM may also be a driving force for circular economy, by preventing environmentally hazardous waste from ending up in landfills and oceans.

The 2030 Agenda has "to take urgent action to combat climate change and its impacts" as sustainability goal number 13 (United Nations, 2021d). In order to fight climate change, emissions of greenhouse gases must be radically decreased. Shifting towards a more localized production could substantially lower the number of transports, both to the production site by reducing the number of suppliers, and to customers by establishing production closer to them, which would decrease emissions from that segment (Shams & Öberg, 2019). Additionally, AM opens up possibilities for product redesign, which could lead to lighter products with less impact during transports (Despeisse & Ford, 2015).

Table 3.6: Sustainability advantages with additive manufacturing, and their conditions

Advantage	***Condition***
Less usage of raw material	If product design is optimized, considering weight
Less waste of raw material	If using recycled material If excess powder is recovered
Less discarded products	If using printing-on-demand
Improved durability of products*	If product design is optimized, considering function
Shorter transports	If switching to localized production If reducing the number of sub-suppliers
Lighter transports	If product design is optimized, considering weight

*Higher durability of spare parts may inversely lead to less resource efficient machines staying in use longer, which may cause an increased level of emissions

As presented in Table 3.6 above, there is no guarantee that AM will have a large positive impact, on the climate unless decisions are made to promote and facilitate this aspect. When implementing AM there are a number of trade-offs to discuss and decide upon, such as whether to keep production more controlled at centralized locations, or to distribute it around the globe to manufacture closer to the consumers. (Bogers, Hadar, & Bilberg, 2016)

4 Case study

This section consists of a case study of Alfa Laval, including a description of the company, their current business situation, and their usage of additive manufacturing. The information was gathered through studying of public documents and conducting interviews.

4.1 Alfa Laval – the company

Alfa Laval is a global metal manufacturer with a long history, operating mainly within three business divisions: Energy, Food & Water, and Marine. Two cross-functional divisions, Global Sales & Services and Operations, exist to support these businesses. With presence in 160 countries, AL is specialized in three technologies in particular: heat transfer, separation, and fluid handling. Globally, they are market leaders within all three areas; with 30%, 25% and 10% of market shares respectively (Alfa Laval, 2020a). Further, AL has three strategic priorities: improving customer interaction, capitalizing on their technology, and continuously increasing their service offering. These are set to reach AL's vision:

> *"To 'help create better everyday conditions for people' by offering efficient and environmentally responsible products and solutions in the areas of heat transfer, separation and fluid handling." (Alfa Laval, 2020a)*

4.1.1 Organizational structure

The three main business divisions contain different value propositions and target different customer segments, while utilizing separate parts of AL's core technologies. All divisions have several business units beneath them, responsible for products related to subcategories of the respective division (Alfa Laval, 2020a). Food & Water offers solutions within all three of AL's core technologies, directed at customers in markets such as dairy, water purification, and waste handling. The Energy division mostly makes use of the heat transfer technology, and has customers in the oil and gas market, as well as in heat, ventilation & air condition (HVAC), among others. For Marine, customers are relatively few and well defined.

This division utilizes all three core technologies, with products used mainly in shipping but also at offshore oil platforms. (Alfa Laval, 2020a)

Many products by Alfa Laval are used by different customers, in business units related to different divisions, but production is not divided accordingly. It is instead a core function of the Operations division. Currently, AL has 39 production units worldwide (Gabrielson, 2021a). Apart from production; procurement, distribution and logistics are also functions being managed by Operations. Procurement aims to perform needed acquisitions and to lower unit production costs, which in 2019 consisted to 70% of direct material cost (Alfa Laval, 2020a). Distribution and logistics are responsible for warehousing, invoicing, distribution, and order handling for all products. Operations Development is also a part of Operations, to constantly improve the division. (Alfa Laval, 2020a)

The second cross-functional division is Global Sales & Services, which has a strong presence in processes for pre-sales and after-sales. Apart from the selling area; the division is related to the entire product cycle and offers general services like installation, maintenance, reparation and spare parts. In 2019, services were accounted for 29% of the annual order intake (Gabrielson, 2021a). Different products have varying need of service and spare parts, but the total value of the aftermarket is potentially higher than that of direct sales. For example, heat exchangers could generate up to seven times the revenue from services compared to their direct sales. Globally, AL has over 100 service units delivering services to more than 160 countries. (Alfa Laval, 2020a)

AL is a public company and thereby subjected to related laws and regulations. On top of this, AL has a number of internal regulations, for example its four business principles, procedures for control and risk, and other governing documents. (Alfa Laval, 2021b)

4.1.2 Strategy

To fulfil their vision and achieve continous growth, three strategic areas are significant to Alfa Laval; to improve customer interaction, utilize technical competences and increase the service offering.

AL uses three business models to improve their customer interaction: a business model where standardized components are sold with a focus on lead time and accessibilty, a configurated business model where slightly adjusted standardized components are sold to specific clients, and a project business model for customized systems and solutions for customers with special needs. These are not strategic business models in a wider sense, but instead describe AL’s value proposition. Depending on the products AL offers within the three business divisions, and who the customers are, different customer relations are established. (Alfa Laval, 2020a)

To capitalize on their technology, AL ensures that their solutions are of high quality and efficiency, which is ensured by consolidating the production to fewer sights. Furthermore, continuous R&D is crucial to maintain their market position. Being at the technological forefront, AL has around 3700 patents (Gabrielson, 2021) and rolls out about 100 new products each year (Alfa Laval, 2021a). The development of new products and solutions can be conducted in collaboration with customers and partners, to further certify desirability (Gabrielson, 2021b). They also try to find new areas of usage for existing products. This innovativeness largely stems from significant annual investments in R&D. AL aims to invest 2,5 % of their annual turnover in R&D. (Alfa Laval, 2021a)

The third strategic priority is to continuously improve the service offering to customers. This includes automation, digitalization, and other investments to form a better overall offering. Improved service may result in both a continuous feedback flow, making it easier to develop solutions according to customer needs, and more returning customers. To help customers minimize, or completely avoid, downtime in their processes, it is important for AL to be quick and present at all locations. As stated, aftersales is an important part of AL's operations, containing large revenue potential from spare parts and services. With this strategic priority, AL aims to capitalize on the potential from aftersales, for example by expanding and improving existing service centers, as well as building new ones. (Alfa Laval, 2020a)

Alfa Laval puts a lot of emphasis on sustainability and contributes to 15 of UN's 17 SDGs. Their four business principles concern the environment, social responsibility, business integrity and transparency, e.g., by optimizing resource efficiency and always working towards high ethical standards. AL's purpose is expressed as "Accelerating success for our customers, people and planet", which includes both the social and environmental aspects of sustainable development. With this purpose and these principles at the core of its operations, AL has incorporated sustainability into its business model. More strategically, they have a goal of becoming carbon neutral in 2030. (Alfa Laval, 2020b)

According to AL, their most prominent strengths are their highly engineered products, large diversification of customers and geographic locations, and their established base of installed products. They are a global company with market leadership in several business divisions and a very strong brand recognition. (Gabrielson, 2021a)

4.1.3 Additive manufacturing

During the past years, Alfa Laval has invested in additive manufacturing, most notably by establishing a technology center in Eskilstuna for research on the technology. Three different AM methods are currently of interest to AL; PBF, BJ, and DED. (Gabrielson, 2021b)

The AM unit is placed under Operations Development, within the cross-functional Operations division (Alfa Laval, 2020a). AM could therefore affect parts manufactured for all three business divisions. Additionally, the offered services could be improved if AM were to be implemented with this focus.

AM is seen as a possible driver for future BMI within AL. The AM unit strives to build an item selection process for it, within Capital Sales and Spare Parts, and visualizes it as a possible future core technology in Operations. They have previously identified six value generating areas for AM: the creation of a digital warehouse, handling of obsolete parts, increased functionality, support of alternative materials, reduced cost, and reduced lead time. (Gabrielson, 2021b)

Depending on which of AL's three business models are being considered, or if new ones are developed, different degrees of innovation might be needed to further create and capture value with the help of AM. To a large extent, AM creates opportunities to improve manufacturing processes, increase customization and support specific solution requests. The technology thereby appears relevant to the existing standardized business model and configurated business model.

4.2 Interviews

When researching AL to gain deeper understanding of the company and its position, interviews were held with people in various roles at the organization and external stakeholders in their supply chain. AM experts from the academic sector were also interviewed to gather knowledge on different aspects of AM, relating to AL and the manufacturing industry. All respondents are presented in Table 4.1. In the following section, important comments and answers from the interviews are juxtaposed and related to specific categories, according to the method for qualitative analysis described by Gioia, Corley, and Hamilton (2013). The aggregate dimensions are presented under five different headings. The conducted analysis, including all themes and dimensions, is visually displayed in Appendix A. More general facts that were received during the interviews, e.g., knowledge on AM, production processes and categorizations of spare parts, were added to section 3 and 4.1.

Table 4.1 Respondents from interviews

Interviewee	*Company/Organization*	*Division/Expertise*
A	Alfa Laval	Operations – Parts, Distribution & Logistics
B	Alfa Laval	Operations – Parts, Distribution & Logistics
C	Alfa Laval	Operations
D	Alfa Laval	Operations Development
E	Alfa Laval	Operations – Global Sourcing
F	Alfa Laval	Operations Development
G	Lund University	Additive Manufacturing – PhD
H	Lund University	Additive Manufacturing – Professor
I	Alfa Laval	Food & Water – High Speed Separators
J	Alfa Laval	Finance – Product Lifecycle Management
K	Metal powder supplier	Welding & Coatings
L	Metal powder supplier	Research & Development
M	Alfa Laval	Distribution Centre Tumba – Order Support
N	Alfa Laval	Food & Water – High Speed Separators
O	Printing system supplier	Sales – Laser Printers
P	Academia	Additive Manufacturing/Business Models – PhD
Q	Lund University	Additive Manufacturing – PhD
R	Alfa Laval	Marine – Separation & Heat Transfer Equipment

4.2.1 Additive manufacturing – an emerging technology

Due to additive manufacturing being an emerging technology, there are lots of visions on future business opportunities

There is much potential for new, radical ideas in the business related to AM. The technology is already slightly implemented on the market but has potential to be applied in many new ways. As the market matures and more actors invest in AM, there could be more successful business cases that in turn may inspire further investments in the technology. On a market perspective, new entrants may be so called printing houses, or hubs, that offer production as a service, which could compete with existing companies in terms of manufacturing. Larger companies might instead vertically integrate, by using AM to print currently procured subcomponents. Both these actions would affect a range of actors in the current supply chains.

For Alfa Laval, AM could improve their service offering by enabling production of spare parts for a wide range of products, not necessarily limited to their own products. By digital transformation, AL could strengthen their service offering further by providing printing on demand for important products. This could for example be performed by agents placed in large marine ports. AM could also be used to improve the product offering, by increasing product capabilities through new design.

AL has had visions of installing AM printers at every distribution center (DC), and close to several large ports. Additionally, they have investigated letting customers print parts themselves. Both these scenarios represent globally distributed manufacturing, where competence is built locally at these sites. Implementing this would require large investments.

Additive Manufacturing is still an emerging technology, lacking proof of technical and economic advantages

Alfa Laval was very positive towards AM a few years ago, with hopes of the technology solving several problems, and with visionary ideas for utilization. However, they are now in a slight phase of disappointment due to slow progress. Since it is still an emerging technology, uncertainty remains regarding profitability, for example regarding protection of IP. Organizational culture and conservative engineers could also hinder an implementation. From a supply chain perspective, the future is dependent on actors making serious investments to make the market trust the technology, by providing economic proof of its viability. AL therefore needs to prove to themselves, their employees, classing societies, and certification institutes that AM is a valid manufacturing method.

When having invested in, and built capabilities for, the technology, there is a need for companies to utilize all hours with the AM machines. However, there are business opportunities that solve the issue of hours not being met, such as leasing a printer to other actors when it is not being used or starting a joint venture with other manufacturing companies – to acquire and own printers together. For AL, it could be positive to own the printers in some way, due to their large number of produced items, either solely or in partnership with other companies.

AM also poses some direct economic limitations. The high investment costs are one obstacle, and the price of metal powder is still relatively high. Large scale production with AM is also held back due to high production costs and limited economy of scale effects. With BJ as production method, larger scale manufacturing is possible, although it imposes more size restrictions on manufactured parts.

More generally, for AM, there are several technical limitations for implementation, one issue being the lack of material available for printing. One metal powder supplier produces nickel-, cobalt-, and iron-based powder for AM, and is currently looking into aluminium, titanium, and copper. Machine suppliers also do research on material, to develop what is requested by customers. As of today, around 95% of AL's products consist of stainless steel, although there are thousands of types of steel that are optimized for specific applications. Therefore, it is challenging to find the right material for each part. Another technical obstacle for AM is that the machines are very slow, and that there are large needs for post-processing, which can be time consuming. It is also a challenge to ensure topological demands, solidity, and low costs of produced products, and to minimize the amount of support material.

Finally, there is still market uncertainty regarding AM, which makes companies unsure of which position to pursue in the future value chain. At the moment, only a very small part of all metal powder on the market goes to AM, although this is speculated to grow in a near future. There are also ongoing collaborations between suppliers of metal powder and suppliers of printers to make sure that the products work together. Despite this, most companies want to keep their expertise internal, and some actors even try to tilt the market to their advantage. For AL, this uncertainty could lead to revenue losses, e.g., if other actors were to supply AL’s customers with spare parts or services. There are also threats that a lack of suppliers, for example of metal powder, will lead to AL being tied to certain actors.

4.2.2 Rising opportunities with additive manufacturing

Additive manufacturing represents both process and product innovation, providing benefits on several areas

AM has the possibility to generate competitive advantage and have positive impact on several aspects of a company’s business model. By using AM, companies could increase their flexibility thanks to lower investment costs for products in small volumes. AM could also lead to lowered production costs and more efficient processes for these products, which would increase economic viability within the manufacturing company.

With AM as production method, there is a possibility to optimize the design of products, which could result in substantially lighter parts than those that are conventionally manufactured. Products could also be customized to fit specific users. This can add a lot of customer value, for example as customized solutions increase a company’s flexibility regarding which orders to pursue. Further, new design can lead to increased functionality and reduce the number of constituent subcomponents that are traditionally processed and welded. The method also creates possibilities for constructions of higher complexity.

A current issue for AL is their long lead times for certain products, which can reach a year in extreme cases. AM could in some cases reduce lead times, especially regarding small articles that are nearly ever produced or ordered, to create substantial customer value. Additionally, a shortened TTM on new products could increase AL's market share.

AM could also contribute to lower environmental impact, which could be used as a sales argument. For example, the AM process generally uses less material than CM, and metal powder can often be made from recycled metal. As products could become lighter with AM, their contribution to climate impact from transports would decrease. The current transportation costs are high at AL, but AM for spare parts could eliminate the need of flying spare parts and reduce other long transports, while still shortening lead times thanks to a globally distributed manufacturing. These sustainability factors could be used as labels for sustainability, to benefit the brand and generate sales.

Utilizing the benefits of additive manufacturing can generate much revenue through increased customer value

Since AM is still a relatively expensive process, items need to add enough customer value to overcome the high costs. Therefore, high-performance products in space, military, automobile, and aerospace industries, among others, can benefit from AM. The same applies for AL; manufacturing cost becomes less of an issue if products have better performance and are charged for a higher price. In many cases, AM can produce more customized solutions and better (e.g., lighter) products, which creates potential within areas of AL where customizability is important. As long as these orders are technically feasible, there is potential for AM. In short, a higher price becomes legitimate as customer value is added in the form of increased functionality.

If the customer needs a certain spare part, e.g., if their production depends on it, AM could drastically increase customer value by reducing the lead time for it. At AL, *red button* is a process that customers can set off, to a certain cost, when they want AL to quickly look into ways of reducing lead time of such parts. If AM could provide an alternative way of producing these, with shorter lead times, the added costumer value could make up for the high production cost of AM. However, it can be difficult to quantify how much value the shorter lead time represents.

For customers, the critical factors are high quality and low cost, not which production method is used. For some parts, 70-75 % of top quality would imply that the part is good enough, while it could be much cheaper to produce. If key customer needs are met; other factors may just have to be sufficient for the situation at hand.

There are many opportunities for additive manufacturing, although several factors must be considered when deciding which to pursue

It is crucial to consider the safety aspects when choosing which products to use AM for. Before considering the technical and economic evaluations, the safety classifications need to be evaluated to determine whether it is even legal to produce an alternative part with AM, as there are laws that prohibit certain components from being too customized. In general, there are more restrictions in design changes for spare parts, which implies that design optimization is generally more valuable in new production. Other benefits, such as producing lighter products, are therefore more valuable for new production than for spare part production.

When looking at specific products or components to determine if they could be additively manufactured, the next aspects to evaluate are the mechanical and physical properties. The part must fit the machine; large articles could be difficult to print due to size restrictions. Subsequently, time and cost aspects must be considered. The economic evaluation is made through minimizing the printing and post-processing costs with the help of design for additive manufacturing (DfAM), and then comparing the costs with those of CM. Even if production is more expensive with AM, it could still be viable due to added value. There are also other factors to consider, such as the supporting subprocesses for AM and specific customer requirements. For example, for Marine customers, cost is important, but lead time is the most critical factor.

In general, AM has most potential to reduce costs for components in small batches. Spare parts and new products that are produced in low volumes are thereby suitable for AM, initially. Other potential areas for an AM implementation could be for products without sub-suppliers, old parts lacking production tools, and products with long lead times. To shorten TTM, AM could also be used for prototypes. All in all, a holistic view of the supply chain is required to determine which products to develop with AM.

4.2.3 Warehousing, service, and spare parts

Complications arise due to Alfa Laval's large base of installed products, and its need of service and spare parts

There are four categories of spare parts handled at the DCs' stock items, business items, non-stock items and request items. Stock items and business items are stored in warehouses, which usually contain around 98% of these parts. Stock items are stored based on demand for the past two years, while business items are stored on requests from business units – for example, these could be parts for recently launched products or parts that are critical for certain customers. The majority of the volume consists of non-stock items, that are delivered from specific sub-suppliers when ordered, which differ from request items that lack a predetermined supply chain and are only handled on request.

AL handles more than 1.2 million order rows each year and distributes more than 350 000 different parts, which are expected to be delivered to customers quickly. Spare parts are offered for products 10 years after they go out of production.

However, orders are common for spare parts to older products, particularly 10-25 years old. In line with the general strategy of AL, the service offering is an important aspect of the aftermarket, and AL is therefore handling customer requests for obsolete products even though they have no obligation to do so.

Due to the large number of existing parts, and because customers request spare parts to obsolete products, AL cannot possibly predict which parts will be ordered. Around 60% of spare part orders are for obsolete products, yet stored spare parts are occasionally discarded when the product is taken out of production. Long lead times and the lack of modern drawings, sub-suppliers or production tools are all reasons to why AL sometimes must deny customers spare parts, even though this outcome is not beneficial to anyone.

The difficulty to predict customer orders result in a somewhat slow-moving inventory. In Tumba, for example, 20% of inventory value is not moving or slow moving. For one product group that was investigated, only half the available parts had been requested in ten years. One reason for the stocking of slow-moving parts is that low frequent products sometimes trigger bigger orders to the manufacturer or supplier, due to volume requirements. On the other hand, space constraints sometimes lead to parts from warehouses being thrown away.

There are several possibilities for AM in relation to warehouses and spare parts. Obsolete products are important in this aspect, as AM could keep providing these with spare parts without having to invest in new production tools. Printing non-stock, or request, items on demand could shorten lead times and increase the service offering of AL. Another suggestion is to work with digital warehousing, which would reduce the need for physical warehousing and therefore bind less capital. For all cases, the specific parts would have to be technically feasible for AM and be reconstructed for this purpose.

4.2.4 Internal support for additive manufacturing

Alfa Laval's products need digital drawings, covered by appropriate protection, to be able to utilize additive manufacturing

In case of an AM implementation in spare parts, a significant obstacle is the workload needed to convert old drawings to digital, AM compatible files. AL has a large product portfolio, and some obsolete products do not even have drawings available, while others are hand drawn.

AL has initiated a cooperation with a class society, with aims to build a digital library for parts. The idea is to build in an identity in each component to combat piracy. Piracy of parts is already a problem within some applications and product ranges, and after converting drawings to digital files, the protection of IP becomes even more important. If AL is to sell digital files directly to customers, for example, the customers' printers would preferably be owned by AL to ensure revenue streams and protect IP. Learnings on how to form this protection could perhaps be drawn from AM of plastics, which is more mature as a technology.

Supporting processes are under development

Another obstacle for an AM implementation is quality control; how AL can make sure that additively manufactured parts have a high standard, even when printed in low quantities. Currently, there are processes under development for quality control of AM products and processes. AM certifications are slow and expensive, and international standards are lacking. Quality assurance is especially difficult in cases where customers are responsible for printing themselves, as a liability issue occurs when products from different printers are of different quality and responsibility is divided between designer and manufacturer. At AL, material specification, quality code and technical delivery specification are used to ensure quality of parts that are made using AM. In March 2021, AL had successfully tested and quality assured around 20 items produced using AM.

In addition to the quality assurance issue, AM demands more general process changes considering how global orders are handled. Currently, AL does not have any standardized way of dealing with incoming orders for AM. A process for handling AM for spare parts has been requested, where technological feasibility would be determined, old drawings would be redesigned, and an offering could be provided quickly to the customer.

Improved software and data structure can support additive manufacturing and improve internal processes

At the present stage, AL has trouble reaching all parts of its large organization, as well as finding and maintaining suitable suppliers to all their products. They also have varying data structure in their different PLM systems, which results in lots of data existing within separate divisions and locations. The same part can even have different serial numbers and looks, depending on where it is produced. Categorizations of products are usually based on production methods and material, which makes it difficult to determine AM suitability from just the category. These are all factors that hinder AL from developing a thorough AM selection process.

AL has identified issues with their divided data structure and aims to include AM compatible 3D-models in their future, more holistic PLM systems. Data from PLM or ERP systems could probably be used to determine which parts would benefit from AM considering their production costs.

In parallel with AM, AL is working with advanced robotics by increasing automation and inserting more sensors in their products. In the long run, this could have AL working with predictive maintenance, where they could predict beforehand which customer parts would need to be replaced. Consequently, their service offering could increase, making them advisors to customers. Software could also give AL other benefits. A logging of settings from PLM or other supportive software would increase transparency and traceability and enable feedback loops in the production process. Virtual manufacturing, where manufacturing processes are simulated before actual production, is another perk of integrated software. The designers could also receive help with design and quality assurance, from features like digital optimization algorithms and digital twins.

4.2.5 Strategy for an implementation of additive manufacturing

Alfa Laval has a clear path for additive manufacturing, including networking and building knowledge

Currently, there is a lack of knowledge within AM in the organization, e.g., among product designers. Education for designers is crucial, but people within the organization might not be willing to quickly adapt. There is also a need for local AM competence at all sites where AM is to be conducted.

AL attempts to tackle this lack of knowledge by investing heavily in AM, and consequently have been able to reach a strong position with just a few large actors ahead of them. However, these investments have to be continuously renewed, to maintain their position and possibly gain even more value if taking the position as leader. AL needs knowledge on AM no matter which strategy and business model to pursue later on. Knowledge building is especially important in Operations, where employees must be prepared to produce and procure AM products, and where AM might later become a core technology.

Apart from internal knowledge building, AL is also contributing to the development of AM on a market level. They are active in a large number of networks and have co-operations with universities, other companies, and governmental instances. AL are also establishing relationships and working closely with several suppliers to increase quality of the final products, for example with metal powder suppliers. In regard to competitors within their core technologies, AL does not have direct knowledge regarding which strategies they are adapting for AM, however they get some insight from their activities in AM networks.

When adopting additive manufacturing, there has to be a holistic approach where business model components and overall strategy are aligned

Alfa Laval has a broad portfolio, with few mass-produced solutions, and mainly manufactures critical components inhouse. Their three business divisions; Energy, Food & Water, and Marine, are the main approaches of their business models, which are shaped by specific clients and their needs. Business models range from large projects with entire production lines to providing single customers with small products. More generally, AL has three strategic purposes; to improve their service offering, build on technology and deepen customer relations. AM aligns with all strategies, by for example giving AL the possibility to further increase their service of low volume parts.

When deciding which manufacturing technologies to implement, important factors to consider are how they affect competitive advantage, efficiency, and product quality. Process and product development must be connected to evaluate this decision. AM is not believed to replace CM for large scale mass production, but instead to be used for niche customer needs. The impact of AM on these small, widely spread markets can be large though. In the situation of AL, AM is expected to act in parallel with core manufacturing techniques and will therefore not compete with these in main production – unless it is widely developed and implemented as a core technology.

AM could have a revolutionary impact on the supply chain, as new designs for products can be made, the number of subcomponents can be reduced, and production chains can be shortened. Company relations could also change, if suppliers upwards were to be removed and new services would be needed for post-processing and quality assurance of printed parts. There is also a risk for manufacturers that customers try to implement AM themselves. The changes to the supply chain are important to consider when discussing effects of AM on business models, even though these may be hard to measure. However, if these factors are quantified, companies could effectively improve their business models to successfully adapt to these changes.

Business model components are all intertwined and related to each other, which is important to consider when determining how they shift in response to changes. When changing the business model, the offered product or service also has to be adapted to fit this change. When implementing AM, the value creation process is directly affected, and different changes may also occur in the elements for value delivery, value capture and value proposition.

AM can affect many layers of the business model, both in incremental and radical ways. Essentially, the effects depend on how a company determines risk and how much they can, and want to, change. The AM strategy then has to align with this.

5 Business model design

In this section, the findings of the thesis are presented. The insights from the literature study are applied to the case study of Alfa Laval, to generate a new business model for metal additive manufacturing. For this, the 4I framework was used, consisting of four different phases, where those included in business model design are initiation, ideation, and integration.

5.1 Initiation

The 4I framework for business model innovation began with an initiation phase, where the current ecosystem was analyzed. The collected information for the analysis is described in section 4. During the initiation stage, it was important to understand the needs of key actors and to identify drivers of change (Frankenberger, Weiblen, Csik & Gassmann, 2013).

The 360° business model framework presented by Rayna and Striukova (2016) is used to visualize the current, general business model of Alfa Laval and to develop a new one for the utilization of additive manufacturing. In this section, AL's existing business model is presented in five tables: one for each element from the 360° framework. The elements were applied on AL's general organization, and thereby cover the entirety of their operations, including all three of their business models with varying degrees of customization, not just specific technologies.

Table 5.1 General business model of Alfa Laval – value creation

	General business model
Core competences	Design and manufacturing of solutions for heat transfer, separators, and fluid handling
Key resources	Competent personnel, production facilities, IP
Governance	Public, listed company – subject to laws and regulations as well as internal business principles and risk management procedures
Complementary assets	Distribution and service centers, brand recognition, global pre-installed base of products
Value networks	Well-developed relations and cooperation with suppliers and customers, competence networks within technologies

As presented in Table 5.1, the value creation aspect is centered around AL's core competencies within their three main technologies. Their key resources and complementary assets are in form of competence, facilities, and large base of installed products. Since AL is a publicly listed company they are subjected to laws and regulations, as well as internal governing documents. Furthermore, AL nurtures their value network of well-developed relations with both suppliers and customers, and more competence-focused networks within specific technologies.

Table 5.2 General business model of Alfa Laval – value proposition

	General business model
Product offering	Products and production lines for Food & Water, Energy and Marine, as well as spare parts for these
Service offering	Product life-cycle services, e.g., installation, delivery, maintenance, support, and reparations
Pricing model	Large variety: some products require lower, more competitive prices, while others are premium products with higher prices

The value proposition is defined in Table 5.2. This is where the three business models mentioned in section 4.1 are all included; the standardized business model, the more configurated business model and the project business model. Further, they will only be referred to as the existing value proposition instead of standalone business models. The product offering consists of a broad portfolio of products and production lines for their three business divisions, including spare parts for the respective products. Life-cycle services such as installation, maintenance, and reparations are part of their service offering. The pricing model varies between different products, which cover the entire spectra from low, competitive prices to exclusive offerings of tailor-made solutions.

Table 5.3 General business model of Alfa Laval – value delivery

	General business model
Distribution channels	Mainly, new products are sold via sales offices and external distributors, while spare parts are distributed by the Service division
Target market segments	All subsegments in Food & Water, Energy and Marine, both established and new customers

AL mainly delivers value, connected to new products, via their own sales offices and external distributors. Spare parts are handled by the Service division, as displayed in Table 5.3. Relevant customer segments are businesses working in different subsegments of AL's three business divisions, both new ones and existing customers owning installed solutions by AL.

Table 5.4 General business model of Alfa Laval – value capture

	General business model
Revenue model	Payments from selling products, spare parts, and services
Cost structure	Material, components, assembly cost, facilities (including machines and the cost of running them), salary, logistics/transportation
Profit allocation	Turnover is approximately 30% after sales, 70% new products

The value capture aspect has a more concrete financial focus. The revenue model of AL is traditional for a manufacturing company; based on sold products, services, and spare parts. Their cost structure is centered around the manufacturing of products, but also includes transportation, salary, marketing costs, etc. As shown in Table 5.4, a significant part of the turnover comes from after sales revenue. For some products, the aftersales market has potential of providing more revenue than the related direct sales.

Table 5.5 General business model of Alfa Laval – value communication

	General business model
Communication channels	Website, social media, customer magazine *Here*
Ethos and story	Long story of reliability and innovation, stands for technological advancement and sustainability

Table 5.5 described how AL communicates their value offering; via their websites, social media, and their customer magazine – *Here*. AL has a long story of reliability and innovation, and their brand signifies technological advancement and sustainability.

5.2 Ideation

Following the initiation phase, the ideation phase was entered (Frankenberger, Weiblen, Csik & Gassmann, 2013), where different ideas for the utilization of AM were generated in collaboration with people at Alfa Laval and external actors. Based on the collected information from the literature study, and specific data on AL gathered in the case study, scenarios were created for the future of AM within AL. The ownership of the printers, their placement, benefits and drawbacks of AM, which parts to manufacture and how to generate revenue are all examples of factors that were considered when creating these. Feedback was collected from respondents within AL to iterate the suggestions further, to come up with strategic roadmaps that corresponded to the needs of the organization.

All scenarios align with the three strategical goals that AL have expressed: (1) protecting/using their technology, (2) developing and increasing their service, and (3) developing their customer relations (Alfa Laval, 2020a). In all scenarios, AM would act as a complement to CM performed by AL, mainly producing single components. Determining an item selection process and developing a larger focus on DfAM, is crucial in all scenarios – especially for old or obsolete parts lacking 3D drawings. Scenario 2 and 3 moves production geographically closer to the customer, potentially involving the customer more in the production and development of products.

Following the interviews and internal discussions of various possible strategies, the scenarios below were developed.

5.2.1 Scenario 1 – Research & Development

The first scenario is that AL owns printers placed in their production centers, focusing on design optimizations in development of new products. This scenario is most similar to the current situation, but AM is more developed and utilized in production. This scenario would work as a supplement to AL's current business model, where new products could get increased capabilities and a higher level of customization would be possible.

The 3D printers would be used for core parts in new products that benefit from AM, e.g., products that could be improved functionally and products in small order volumes. Heavy investments would be made in R&D. Some of the products would become cheaper to produce, which could increase AL's profit and/or lower the price for customers, enhancing the value proposition. Other products would obtain added value due to improved capabilities, for example functionality, which could change the pricing model. Most of the production would still be using conventional methods, and logistical operations would remain the same. For certain subcomponents, previously bought from suppliers, vertical integration could be of consideration if AM could provide these parts faster or to lower costs. In this scenario, some changes would occur in the network structure, as relationships to metal powder suppliers would have to be prioritized and the number of suppliers of subcomponents could decrease.

5.2.2 Scenario 2 – Service & Spare parts

In the second scenario, AL owns the printers, but these are placed at a large number of distribution centers. This is a relatively incremental scenario, where AL can invest in and install printers in places where they have supporting operations. It would require large investments, but could potentially generate a lot of value to AL. While not changing the process for new products, AL could decentralize their production of spare parts geographically, insource production of some parts and enable deliveries of parts for obsolete products that are currently difficult to procure and produce.

Mainly spare parts would be produced in this scenario, which is divided into two sub-scenarios focusing on different categories of spare parts. Large investments are needed to buy printers and to build expertise locally to reconstruct parts, operate the machines and handle post-processes. In the case of printing non-stock, obsolete, and especially request items (scenario 2a), AM could lead to significantly improved lead times and environmental impact, due to simplified production chains and shorter distances for transportation. Red button orders would be important in this case, which are when customers are requesting items for lower costs or shorter lead times. In the other case of printing stock items (scenario 2b), warehousing costs could be reduced, or the stock could be optimized, if printing-on-demand were to be utilized for some parts. In both cases, AL would need to develop a new network structure, preferably with metal powder suppliers close to the printing locations, and with local companies providing support processes. The revenue streams would generally stay the same as revenue would still be gained from providing spare parts, though the involved services would change, and could somewhat increase, if utilizing AM.

5.2.3 Scenario 3 – Digital warehouse

In the third scenario AL do not own printers, except for R&D purposes or together with customers. Instead, they utilize AM by developing digital files to generate a digital warehouse, that customers can choose parts from to print themselves. This would be the most disruptive scenario, demanding a radical addition to AL's business model, for example in terms of key activities and revenue streams, but also value proposition. The scenario would require organizational transformation, as parts of AL would go from a manufacturing company to a company solely for solution design.

In this case, AL would offer some parts as digital files instead of physical products. Customers and logistics companies could buy the files and print for themselves, with more or less manufacturing support from AL. The cost could either be paid as a license, a subscription, or a one-time cost. AL would have to come up with valid offerings and relating revenue models to be beneficial in this scenario. It could lead to less capital being tied up in production and warehouses, while AL would remain an expert in solution design. Problems considering product quality and IP would also require evaluation, in relation to the increased usability and accessibility. The scenario would not be applicable for all products, as AM cannot be used for all sizes or materials, which implies that most of the CM at AL would continue as usual.

5.2.4 Feedback

The received feedback from people within AL showed that they had different views on the likelihood of the respective scenarios. However, the respondents generally believed a combination of several scenarios to be the most effective. The advantages and disadvantages of each scenario are defined below in Table 5.6.

Table 5.6: Advantages and disadvantages of the scenarios

Scenario	*Advantages*	*Disadvantages*
Scenario 1 – Research & Development	Feasible Relatively low risk Enables incremental knowledge building	Not innovative or exciting Economic gains dependent on future findings
Scenario 2 – Service & Spare Parts	Economic incentive for urgent request items; red button orders Shortened lead times Possible to provide parts otherwise not available Reduced transports leading to lowered climate impact	Large investments needed, in machines and competence More contact required with local suppliers Many products needing redesign of drawings
Scenario 3 – Digital Warehouse	Innovative Shortened lead times Lowered warehousing costs Reduced transports leading to lowered climate impact	Radical, risky Difficulties with IP protection Difficulties with quality control

As scenario 1 is the most similar to the current situation, it was generally viewed as feasible, although perhaps not the most desirable one. Spare parts were suggested to be included in this scenario as well. Several respondents noted that 2a would be an interesting continuation from scenario 1, and that this growth could potentially even continue to scenario 3. That way, the development could follow an incremental path starting with an implementation of scenario 1, followed by an acquirement of printers at various distribution centers, all while creating a digital warehouse as more 3D files were drawn and tested.

Scenario 2 was not seen as plausible as a first step, largely due to the large need for local competence at the different locations, regarding AM and related supporting processes. There would be a need for both internal education and a cluster of sub-suppliers at each DC with a printer. Additionally, since AL is offering hundreds of thousands of different parts, there would be an obstacle to convert old drawings to 3D files. However, this wouldn't have to be an issue if products were initially chosen a few at a time, going through a relatively simple but comprehensive technical and economic evaluation process. For example, using items from red button orders as AM candidates could provide economic incentives for designing 3D drawings for these spare parts, as they were already requested by customers. The respondents more or less wanted scenario 2a to be implemented, although they had different timeframes on when that implementation would take place. Scenario 2b is slightly more uncertain, as stock items are usually produced in such large batches that AM might not be a viable solution. Warehousing costs did not appear as that large of an issue in relation to the benefits of having stored parts ready for delivery. There was some interest in it however, although in an even longer timeframe. Some of these items could be manufactured using AM if cost savings could be found in their production chain, although it seemed more desirable to start with other parts.

As for scenario 3, protection of IP was of high priority. Some of the respondents believed that AL could print certain components inhouse, and some via external actors. If this should be worth considering, it was crucial that the printable files would not be shared to other recipients or be printed more than once. Lacking IP-protection creates possibilities for AL to manufacture spare parts for any product, but also increases the risk of other companies copying AL's products. Another question arose regarding having the customer as the producer – who would then be responsible for quality assurance? One way to prevent these issues would be by allowing customers to have AL's printers in their facilities, printing via AL's network. Consequently, the files would never spread outside of AL's organization, while the lead time and transportation costs could be radically reduced. One respondent added their own version of scenario 3, where instead of selling files to customers, AL could let suppliers print their products for them. This would mean that AL would only have to design the products, while not manufacturing them inhouse. Just as the first version of scenario 3, this poses a large risk regarding IP, as AL would have to share their design with external actors.

Scenarios 2 and 3 are especially desirable in the view of sustainability questions, as these scenarios are driving the lowered climate impact of transports, due to globally distributed production. They are also shortening lead times the most, which according to a respondent is an ever-growing demand from customers' point of view. This is important for manufacturers to consider, as the threat of piracy increases when lead times on their products are too long.

5.2.5 Scenario 4 – A combined solution

Following the feedback on the initial scenarios, a fourth one was developed to base the new business model on. This recommended scenario became a combination of the ones above, where benefits of several scenarios were highlighted, and aspirations and concerns of internal stakeholders formed an open-ended strategy with risk aversion at a higher priority. R&D for new products, an increased offering of spare parts and a digital warehouse for internal usage were merged into one scenario.

For this scenario, investments should be made in printers at a few strategically located distribution centers, spread out globally. The focus would initially be on items in red button orders; low volume spare parts that are urgent to the customers. These parts could be difficult to produce or procure conventionally, and an AM offering could therefore be a valid and valuable alternative to the customers. If an evaluated part would be considered technically feasible, and the offer accepted by the customer, a new 3D drawing could be developed and added to an internal digital database of drawings. The main advantages in this case would be the drastically shortened lead times, as well as an improved ability to produce spare parts that would otherwise have been hard to provide.

A considerable amount of AL's environmental impact is from flight transports of spare parts that need to be delivered quickly. Especially regarding red button orders, short lead time is critical, and in today's operations this is often solved by using air transport. Having printers at DCs would partly diminish this issue as urgently needed items could be produced locally, closer to customers. Additionally, as AM enables redesign and potentially lighter products, emissions could be reduced during production and transport, further lowering the total impact. The scenario therefor aligns with AL's goal of carbon neutrality 2030 (Alfa Laval, 2020b), and could have impact in realizing it.

Simultaneously, with this new supply chain for certain spare parts, major design changes in new products would be investigated in R&D, as some of the biggest benefits of AM lay here. This would mainly be focused on improving product functionality but could also lower costs or shorten lead times for niche components. To utilize the printers, and provide both short and long-term revenue, this research would be performed continuously whereas spare parts would be prioritized when interesting cases arose. After an ongoing period, with simultaneous R&D and deliveries of additively manufactured spare parts, further analysis would be conducted to determine where AM would be most profitable within AL.

5.3 Integration

The third step of BMI, according to the 4I framework, is integration, where the key activity is to build a new business model (Frankenberger, Weiblen, Csik & Gassmann, 2013). To develop a new business model for Alfa Laval; the 360° framework was applied to the fourth scenario. Based on the general business model of AL, from section 5.1, the AM scenario was added to determine where and how the business model would change. The new business model was created as a compliment to the general business model and is not supposed to be a substitute. As the AM technology continues to develop, the importance of this part of the business model may grow.

Table 5.7 General and AM business model of Alfa Laval – value creation

	General business model	*Business model for AM*
Core competences	Design and manufacturing of solutions for heat transfer, separators, and fluid handling	DfAM, redesign and reconstruction, post-processing, and item selection processes
Key resources	Competent personnel, production facilities, IP	3D printers, digital warehouse, software for design and production
Governance	Public, listed company – subject to laws and regulations as well as internal business principles and risk management procedures	Increase collaboration between the AM team in Eskilstuna, Operations Development, and the Service division. New processes and standards are under development
Complementary assets	Distribution and service centers, brand recognition, global pre-installed base of products	Distribution centers, 3D printers owned by other actors, global pre-installed base of products
Value networks	Well-developed relations and cooperation with suppliers and customers, competence networks within technologies	Relations to metal powder suppliers and post-processing suppliers, collaborations with customers, competence networks such as CAM2

In comparison to the existing, general business model of AL, see Table 5.7, an implementation of AM would require large investments in education. This would require competence at all locations where AL planned to get a printer, namely at the selected distribution centers, and education within design, post-processing and item selection would be key factors for success. As more and more 3D drawings would be created and tested, the digital database of drawings would grow and become a key resource. Regarding the governance of AM, the Service division that is responsible for customer requests would look into if AM could be a viable alternative for specific parts and then pass them onto the technology center in Eskilstuna for further evaluation. When implementing AM, new processes should be developed on how to handle orders and follow standards. The value network is also expected to change in the case of AM. The most important suppliers would somewhat shift from producers of subcomponents into metal powder and printer suppliers. Thanks to the increased level of customizability, AM might lead to a deeper collaboration with customers. Since the technology is very new and still evolving at a fast pace, it is crucial to keep gather information on its development, for example via competence networks with other actors.

Table 5.8 General and AM business model of Alfa Laval – value proposition

	General business model	*Business model for AM*
Product offering	Products and production lines for Food & Water, Energy and Marine, as well as spare parts for these	More sustainable products with increased functionality and customizability
Service offering	Product life-cycle services, e.g., installation, delivery, maintenance, support, and reparations	Shorter lead times for spare parts, lower environmental impact, providing spare parts for more obsolete products
Pricing model	Large variety: some products require lower, more competitive prices, while others are premium products with higher prices	Sell products and parts at a higher price for premium offerings (utilize added costumer value), the same price (utilize cost savings) or a lower price (utilize more sold items)

Table 5.8 demonstrates the difference between the general value proposition and that of AM. The product offering with AM would have a stronger focus on sustainability, functionality, and customizability than AL's general product offering. For example, there would be a possibility to decrease the amount of raw material used in production, and to produce items with higher quality, prolonging their lifetimes. These aspects support SDG number 9, regarding industry, innovation and infrastructure, and goal 12 of responsible consumption and production. The changes in the service offering reflect the shortened lead times and the lower environmental impact, especially SDG no. 13 regarding climate action, due to shorter transportations of goods and fewer flight transports. AM also opens up an opportunity to manufacture spare parts for more obsolete products, which would be an important service improvement for some customers.

There would be three distinct pricing models with AM, depending on which benefit AM provided. In the first case, AM could raise prices due to increased customer value. The increased customer value would be especially relevant for new products and could be achieved by better products and lowered environmental impact, but may also be applied for improved service of spare parts. In the second model, the price would be the same as for CM, although the profit margin would increase as a result of lowered production costs. The third would be to keep the same profit margin as before, although increasing revenues due to accepting otherwise denied orders. For example, if a customer deems the price of a spare part too high and wants to cancel the request, AL could attempt to use AM to provide the item to a lower cost. For AL, red button orders could use both the first and the third pricing model. This depends on if the customer receives an improved service offering, due to lower lead time, or is offered a part that previously would have been too difficult or expensive to acquire.

Table 5.9 General and AM business model of Alfa Laval – value delivery

	General business model	*Business model for AM*
Distribution channels	Mainly, new products are sold via sales offices and external distributors, while spare parts are distributed by the Service division	Products could be printed near the customer at a distribution center
Target market segments	All subsegments in Food & Water, Energy and Marine, both established and new customers	Existing customers of AL with installed products. To begin with, smaller niched segments are viable. Further on, other business units could be investigated for R&D

Table 5.9 shows the shifts in value delivery. The distribution channels would not change radically, although the production may be moved significantly closer to the customer, which could lower transportation costs and the environmental impact – strengthening the work towards SDG number 13 of Climate action. To begin with, the target customers would be existing customers of AL with installed products, to further the service offering of spare parts. For new products, small, niched customer segments could be evaluated for viability due to increased customization, and larger, more critical parts within various business units could be researched for improvement.

Table 5.10 General and AM business model of Alfa Laval – value capture

	General business model	*Business model for AM*
Revenue model	Payments from selling products, spare parts, and services	Payments from selling products, spare parts, and services
Cost structure	Material, components, assembly cost, facilities (including machines and the cost of running them), salary, logistics/transportation	Raw material, facilities (printers and running cost), salary, software, post-processing cost
Profit allocation	Turnover is approximately 30% after sales, 70% new products	Short term focus on spare parts, long term focus on R&D

In Table 5.10 the value capture aspect was analyzed for AM. The revenue model would be similar to the general business model of AL, where payments would be received from customers in exchange for products and services. Compared to CM, the cost structure would change by becoming more dependent on marginal costs and less affected by fixed costs. Potentially, the costs could be lowered for raw material and from procurement of subcomponents, although expensive investments in printers, process improvement and competence would be needed. Initially, focus would be on the production of spare parts, while the long-term focus would be on incorporating the technology with the rest of production.

Table 5.11 General and AM business model of Alfa Laval – value communication

	General business model	*Business model for AM*
Communication channels	Website, social media, customer magazine Here	Website, social media, customer magazine Here
Ethos and story	Long story of reliability and innovation, stands for technological advancement and sustainability	Long story of reliability and innovation, even stronger focus on technology, sustainability, and customer service

The value communication aspect is displayed in Table 5.11. This would not change significantly by an AM implementation. The clearest change is that the ethos for AL would be even more focused on technology, sustainability, and customer service.

6 Business model realization

This section concerns the final phase of the 4I framework: implementation. Unlike the previous three phases, implementation concerns the realization of the findings. Featured in this section are an implementation plan, two separate item selection processes and a business case.

6.1 Implementation

The fourth, and final, step of the 4I framework for business model innovation revolves around the implementation of the new business model. In this section, a step-by-step implementation of the business model for additive manufacturing is presented, focusing on how Alfa Laval could overcome internal resistance, secure relevant resources, and ensure future revenue streams (Frankenberger, Weiblen, Csik & Gassmann, 2013). The most prominent uncertainties and the actions needed to minimize these are brought forward to strengthen the implementation and mitigate the risks associated with it. The three steps are demonstrated in Figure 6.1 below.

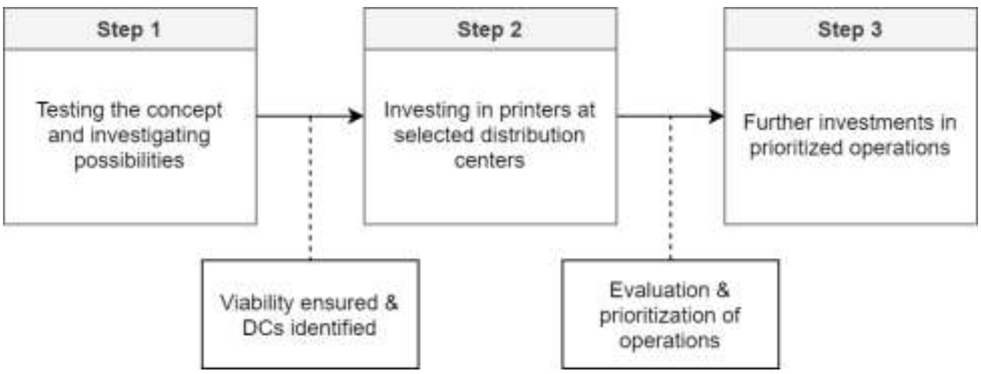

Figure 6.1 Step-by-step plan for additive manufacturing implementation

6.1.1 Testing the concept and investigating possibilities

The first phase of an AM implementation would be dedicated to test the utilization of AM at the technology center in Eskilstuna, to evaluate if it would be organizationally possible to manufacture products for red button orders at the same time as research on major design changes is conducted for new products. Relevant software to support the new processes, such as a system for internal AM orders and a common data structure for storing digital files, would have to be procured externally or developed inhouse at this stage. Simultaneously, a search for strategic AM locations would be conducted. Distribution centers located where many orders are received, probably where the established product-base is significant, are especially of interest. It is also necessary to investigate the presence of competence and local suppliers that would be needed for this expansion, for example regarding post-processing and metal powder supply.

6.1.2 Investing in printers at selected distribution centers

Before initiating step two, a sufficient number of AM parts must have been handled, to ensure viability of the expansion. The investigation on DCs would also have to be finished, to be able to determine which ones would benefit most from acquiring AM. If spare parts produced with AM are successfully providing revenue, and strategic DCs have been identified, the implementation moves on to the next level.

The R&D would remain as in step one; although step two should include an incremental investment, setting up AM at a few strategically selected DCs. The distribution of AM would require local competence to be built, and AM networks to be expanded, at these locations. Knowledge on how to handle incoming orders, how to reconstruct and redesign parts, post-processes for AM and operating the production would be crucial resources at each DC with a printer. Some parts would need to be manufactured in-house, while some could be produced with the help of external actors. This step is performed in small scale to test and validate the viability of the solution, to see if the distributed printers are sufficiently utilized, if it is possible to build the necessary competence and network to conduct AM, and if it adds enough value to AL and their customers.

6.1.3 Further investments

Before moving on to the third and last step of the implementation, an evaluation of the operations is needed. If one of the two aspects of AM shows to be more successful than the other, that part should be prioritized. For example, if the development of products with major design changes would generate more revenue than spare parts produced with AM, new production should receive more investments. However, if the process at the distribution centers provides substantial customer value and AL is able to generate revenue from it, further investments in AM should be of interest in this application.

The third step consists of further investments in the AM operations. At this stage, AL is also recommended to invest further into software, depending on their needs in the AM process, for example in programs used for virtual manufacturing and simulation. Additionally, if both areas were to be successful; this could call for organizational innovation, where the AM division would be split into subdivisions. These could be specialized in different areas of AM utilization, for example, in R&D for new production and in reconstruction of request items. If none proves successful, AM could instead be approached solely in collaborations with external suppliers.

6.2 Item selection process

To determine which parts to produce using AM, there is a need for an item selection process to evaluate viability, feasibility, and prioritization of relevant parts. In the case of Alfa Laval, the products seen as potential AM candidates are either new products, requiring major design changes, or spare parts, that generally only require - and allow - minor design changes. Since there are different benefits and demands in each product category, two different selection processes are needed.

6.2.1 Spare parts

Considering spare parts, specifically request items, the main drivers for implementing AM are shorter lead times, cheaper products, and lower environmental impact. Printing these on-demand at sites closer to the customer would reduce lead times, decrease the length of transports, and reduce the need of delivery by flight, leading to lowered climate impact.

Figure 6.2 demonstrates a flowchart that aims to show the path that a spare part order could go through, to determine if an AM offering should be presented to the customer. To *determine AM possibility*, the request should be evaluated regarding legal and safety aspects, and then be sent to an AM expert to do a quick estimation on technical feasibility. If the part exhibits technical feasibility, lead time and production cost are estimated for the customer offering. As an example, a list of factors to evaluate is displayed in Table 6.1.

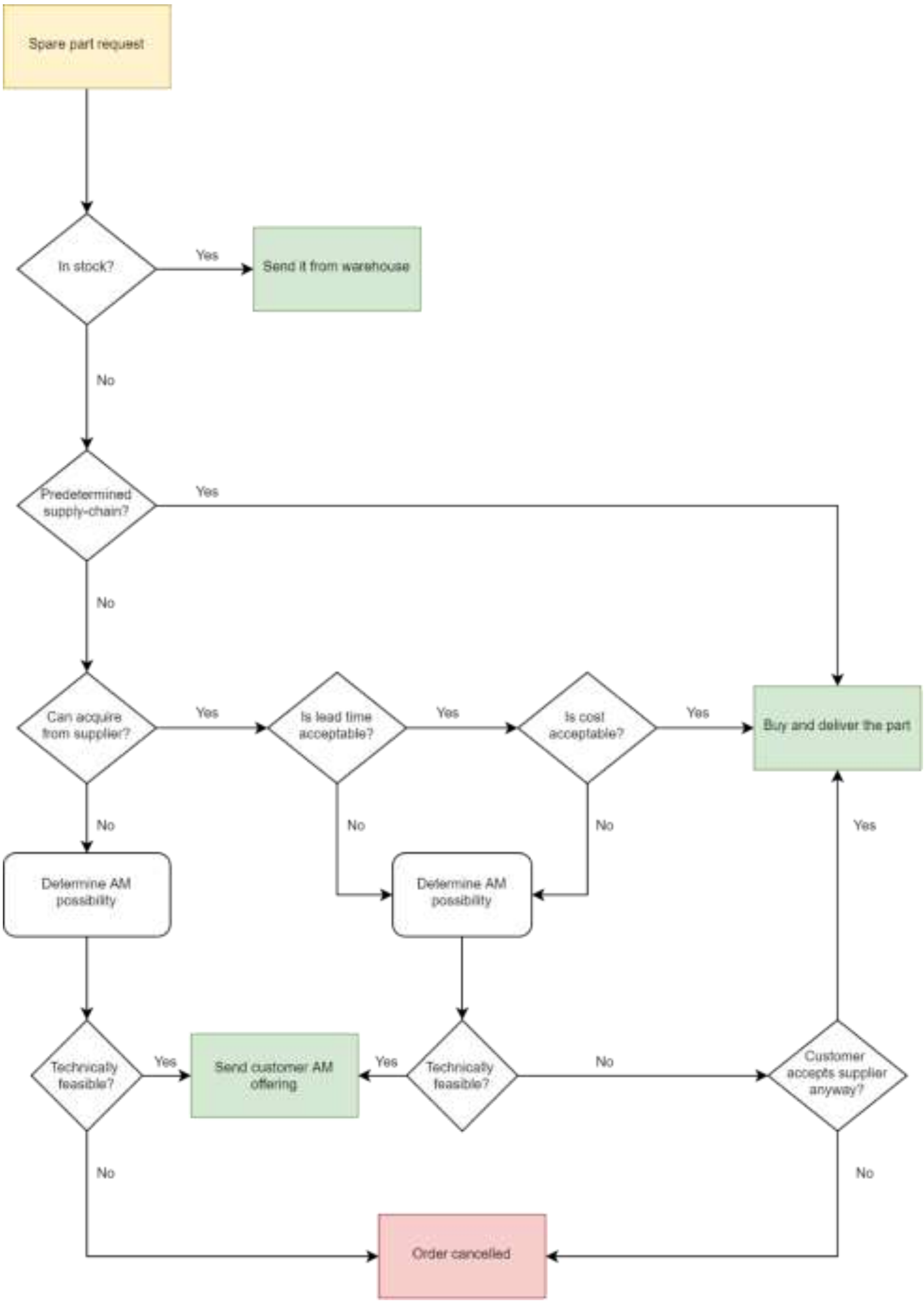

Figure 6.2 Flowchart for incoming orders of spare parts, with additive manufacturing implemented

Table 6.1 Determine AM possibility (spare parts)

Criteria
Are there any security classifications that stop an eventual printing?
Is the size possible to print?
Is there printing material available that holds acceptable quality for the part?
Is the design possible to print?
Can the functionality be maintained, or improved?
How long will a 3D drawing process take?
How long will the production and post-processing take?
How much will it cost?

The questions in Table 6.1 are mainly concerning the feasibility of AM for requested spare parts; for example, if there are security classifications that could affect the redesign and if the structure of the component is within the given size restrictions. If the part is estimated to be possible to print legally and technically, the questions of time and cost are the next to examine before an offering can be presented to the customer. One of the main reasons to use AM for these items is to shorten the lead time, hence printing and post-processing times should not be too lengthy. Acquiring request items from suppliers can be costly, and therefore AM should preferably be a cheaper alternative to be worth considering for the customer. If the part is feasible, and the customer accepts the estimated offering, it goes through to the next step of the process, where more in depth evaluation and manufacturing is conducted.

Regarding spare parts that are stored in warehouses, another item selection process would be required to determine their AM feasibility. Critical factors would remain similar to those of requested spare parts, but AL could benefit from reducing their stored stock and create customer value in form of increased capabilities. The selection process could somewhat resemble the one for new products described in section 6.2.2, however, other factors would have to be evaluated to determine economic viability. These could for example be inventory turnover, warehousing cost, and disposal rates.

6.2.2 New products

In opposite to request items, where there is a stated demand and the items might be difficult to acquire without AM, new products need to compensate for the potential increased production costs with added value or larger cost savings. In order to find relevant products, there is a need for categorization of the components, highlighting the areas where AM could be adding value. These aspects could be increased functionality or lighter products as value-adding factors that could legitimize a higher price for the customer, or a simplified supply chain that could lower the internal costs for the company. Another difference between the item selection process for components in new products, compared to that of requested spare parts, is that this process would act as a grid to select the most suitable parts from the entire portfolio of parts at AL. This is a larger, more thorough process that requires more from AL's data structure, whereas the process for spare parts just needs data on specific parts as they are requested. For new products, the initial selection could perhaps be conducted somewhat automatically, if the selection is based on available data. Table 6.2 demonstrates a few questions that could be used as the first filter for finding candidates.

Table 6.2 Item filtering for AM candidates (new products)

Criteria	***Filtering answer***
How large is the demand?	< 100 per year*
How large is the item?	< 400 * 400 * 400 mm
Does the item consist of several subcomponents? (That AM could reduce)	Yes

*Dependent on the size, smaller items could be of interest even in larger batches and vice versa

As stated in Table 6.2, relevant factors to consider are, for example, if the part is produced in small or large batches, if it is customized for each customer, and the design (e.g., number of subcomponents and size). Although quantifiable data could help initially, AM expertise is required to determine which benefits to pursue and what to prioritize later on, in addition to determining actual feasibility. At this stage, the questions in Table 6.1 are relevant, although more focus should be put on how certain design changes could improve product capabilities or reduce internal costs. In opposite to the feasibility investigation on spare parts, that only considers minor design changes, this evaluation cannot be solved in a binary manner. Determining if new product parts are AM suitable is more complicated, since there are more trade-offs in regard to, for example, how much the customer is willing to pay for an improved product, or if increased production costs can be outweighed by added value elsewhere. A simplified example of the selection process for new products is visualized in Figure 6.3.

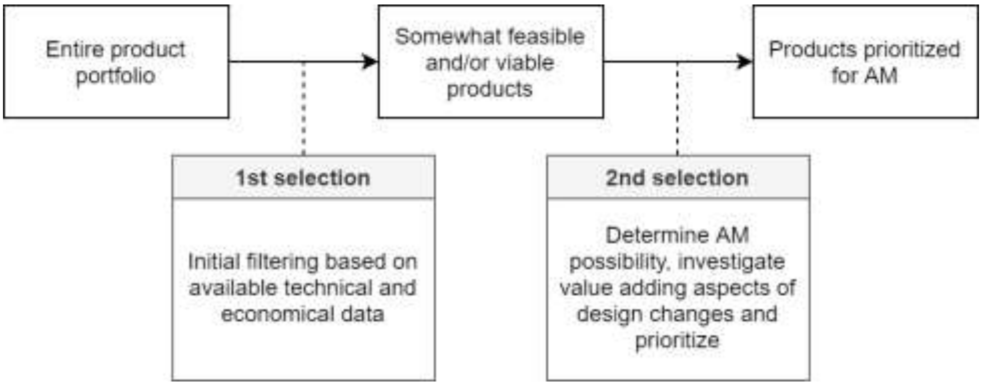

Figure 6.3 Flowchart for the item selection process among new products, for additive manufacturing

Most of the data needed for an AM item selection and feasibility determination can be found in PLM, ERP and CRM systems. To facilitate the process of evaluating AM suitability, AL should make an effort to work on a unified system.

6.3 Business case

In order for AM to be viable for red button orders, the cost of AM cannot exceed the willingness to pay of the customer. A rough cost calculation on one item could be to weigh the production costs (material, salaries, running costs, etc.) against the value of shortened lead time, e.g., how much a customer values receiving an item *x* days before the alternative.

Table 6.3 Cost calculation for a spare part produced with additive manufacturing

Factors	***Cost (SEK)***
Material	*2100*
Setup	*900*
Processing	*15 000*
Post-processing	*12 000*
Total	***30 000***

Table 6.3 displays an example of a cost calculation for producing an item with AM, while Table 6.4 shows the lead time of this production. In this case, the total cost of

the item is estimated to 30 000 SEK. The lead time of an alternate supplier, or Alfa Laval's CM process, has a lead time of 5 weeks, or 25 working days, while the lead time of the AM process would be almost 12 days, as shown in Table 6.4. This concludes that manufacturing with AM could save about 13 working days, compared to the conventional process. If dismissing the alternative costs, the customer would have to be willing to pay about 30000/13 ~ 2300 SEK per day of shortened lead time. If this price is reasonable or not is up to the customer, which could be weighed against factors such as if the spare part is a critical item in production and how much revenue is lost per day without it.

Table 6.4 Estimated lead time for a spare part produced with additive manufacturing

Activities	***Time (days)***
Feasibility evaluation	*1,5*
Generate offering (price and lead time)	*1,5*
3D drawing	*2*
Setup	*0,25*
Printing	*1*
Post-processing	*3*
Quality assurance	*2*
Total	***11,25***

Depending on the value a customer allocates to one day of shortened lead time, the manufacturing cost might need to be minimized as well. This could potentially be done by reduced product weight (thereby lowered material costs) or by optimizing production in other ways. This relation is described in the equation below.

$$c(AM) \leq \big(LT(CM) - LT(AM)\big) * v + c(CM)$$

$$c(AM) \ = \ cost\ of\ additive\ manufacturing$$
$$LT(CM) \ = \ estimated\ lead\ time\ of\ conventional\ manufacturing$$
$$LT(AM) \ = \ estimated\ lead\ time\ of\ additive\ manufacturing$$
$$v \ = \ value\ to\ customer, per\ day\ of\ shortened\ lead\ time$$
$$c(CM) \ = \ cost\ of\ conventional\ manufacturing$$

As the equation above demonstrates, the cost of AM cannot exceed what the customer is willing to pay for the shortened lead time. What the customer is willing to pay is represented on the right side of the equation; as the difference between the estimated lead time of CM and that of AM, multiplied by how much value one day of shortened lead time is to the customer, and lastly the cost of the alternative item made from CM is added. In short, the customer would be willing to pay the same price as for the traditional item, plus the value of the saved lead time. For AM to still be viable for spare parts in cases where the value of shortened lead time is low, cost savings would have to be made due to the change of manufacturing method.

As this case just considers one item, and determines if it would profit from AM, the calculation is not generalizable for wider usage. However, the equation does display some aspects worth evaluating when determining if a specific part would benefit from AM production, especially regarding how these aspects relate to one another. On a larger perspective, it does not involve alternative usage of machines, as it only considers one problem in isolation. Weighing different utilizations of AM against each other will be important when implementing AM, but as income from R&D is hard to determine it is difficult to include this aspect in every decision. This wider comparison is instead recommended when deciding upon strategic decisions for AM, and the data for these would preferably be taken from a large number of practical cases, during a set period of time.

7 Discussion

In this section, the methodology and the results are discussed and validated. The data gathering and analysis are evaluated based on generalizability, reliability, and validity; while the generated business model for additive manufacturing is evaluated based on three criteria: feasibility, viability, and desirability.

7.1 Evaluation of results

Using the received feedback from stakeholders within Alfa Laval, the business model was evaluated based on feasibility, viability, and desirability. Some of the questions raised by the stakeholders are stated in Table 7.1 below.

Table 7.1 Challenges of the business model for additive manufacturing within Alfa Laval

	Business model for additive manufacturing
Feasibility	Can the AM team really let go of their work on new products each time a red button order is received? Do they have the capacity to handle these?
	Is there enough knowledge on AM at the selected DCs?
	Could partners be included to support the distributed manufacturing process?
	How is quality assured when lead time is critical?
Viability	Are red button orders enough to utilize the printers?
	Will the printers at each DC be utilized enough and provide enough revenue to cover the investment costs?
Desirability	Can AM provide an even better service offering by focusing on other spare parts than red button orders, for example those stored in warehouses?
	Should the red button process really be of higher priority than R&D?

Several respondents questioned if it was feasible that people within R&D should prioritize producing and redesigning spare parts when they were working on something different, and if there are enough red button orders to reach viability. In the first step of the implementation, red button orders will most likely not reach a utilization rate that is sufficient to fill a printer. For that reason, R&D will be conducted simultaneously on new products, representing the main, continuous work. When urgent red button requests are received however, some of the AM experts shift their focus to evaluate that item’s AM suitability. This should be a priority, as these orders could provide substantial customer value and provide short-term revenue, while R&D may contribute to long-term income and stability. To reach viability, there is a possibility to expand the R&D investigations by looking into other areas than product development, for example printing casting dies or other categories of spare parts. This improved, widened service offering would also lead to increased desirability. Which utilization to prioritize, and which areas of R&D to investigate, would be further decided after the initial implementation, where full scale R&D and spare parts handling would be conducted in parallel and evaluated.

Regarding the capacity to handle red button orders, orders are not sent directly to the AM team, but goes through an initial evaluation by the service unit, described in the flowchart in section 6.2. This removes most of the administrative workload from the AM engineers. If the demand would increase, investing in new personnel and expertise could be considered to divide the team into groups focusing on separate utilizations. The quality assurance of AM-products is another issue that considers the feasibility of the manufacturing process. To ensure that parts of high enough quality are delivered, the determination of AM possibility has to take these specific requirements into account, where items with too high demands on quality are not considered suitable.

When discussing whether it is viable to have printers at several locations, this is to be more thoroughly evaluated during the initial implementation. The first step of the implementation will consist of a slow expansion on the current location, while investigating if a further expansion would be viable and at which DCs the other printers could then be located. Even if red button orders could not make this investment viable on their own, new findings in R&D or a widened utilization of AM in production or spare parts, could argue for an implementation of globally distributed printers. At the same time, knowledge and networks would be built at the selected DCs to strengthen the feasibility of the operation.

If an expansion to other sites is estimated as unfeasible, new supply chains with globally distributed suppliers of printing services could instead be of consideration. Taking advantage of external knowledge could also be used in combination with internal usage of AM, for example regarding items that could benefit from a method or material not available within AL. Additionally, this could be of consideration if the capacity of personnel and facilities is too low, to send requests to an external actor that has knowledge in AM.

7.2 Discussion of results

The results were also discussed regarding how they contribute to stakeholders in different areas, such as to the academia and to Alfa Laval themselves.

For the academia, the thesis results contribute to the lacking research identified by Öberg, Shams and Asnafi (2018), regarding potential value propositions for AM, different revenue models that can be applied with AM, and the role of manufacturing actors in the new supply chains.

As AM widens the potential product and service offering, prioritizations regarding which aspects to address have to be made by each actor involved. Which benefits to focus on may be limited by financial or organizational factors, but for large, innovative actors; investing in AM can pose a relatively low risk if AM is meant to complement the existing business. This way of reducing risk is further supported in literature by Bucherer, Eisert and Gassmann (2012). Different benefits of AM are utilized in separate value propositions, and the needed competence for successful implementations may therefore vary. If a strong service offering is considered suitable, a company might need to develop internal order processes to enable quick on-demand manufacturing. Instead, if more efficient parts with lower environmental impact are of interest, investments will have to be added to R&D and software that enables design optimization and production simulation. Connected to each value proposition, and choice of item to produce with AM; a fitting pricing model has to be developed. Depending on the driving value adding aspect the importance of price for the customer varies, and the profit margin potential therefore depends on the underlying reason to use AM.

As value propositions vary, so does the related revenue models. Apart from the usual revenue model, where money is received for specific products and supporting services, AM creates several alternatives. The printing machine could for example be leased, to generate revenue from subscriptions and insurances. This could lower investment costs and provide a more predictable cash flow. If owning a printer, other companies could be allowed to buy print-jobs to utilize printing time, generate profit and contribute to the development of the technology. Another revenue model is related to the distribution of digital files, which could let companies become experts in design while not being responsible for the manufacturing. As mentioned earlier, this scenario creates legal issues because of non-existent standards and poses large risks regarding quality assurance and the protection of IP. It is therefore important to know how other actors could benefit from a company's designs, and vice versa, before it is worth considering.

Depending on how AM is utilized, manufacturing companies can reduce the number of suppliers needed in their supply chain, by vertically integrating to create more subcomponents inhouse or reducing logistical operations. In all cases however, the role of the manufacturing company remains similar to their current role, even as AM becomes a more widely spread technology. This is due to the niche usage of AM today, a limitation that stops AM from replacing existing methods of manufacturing for mass produced products. In the current state, AM can therefore only be used as a complement in cases of metal mass production, which stabilizes the role for manufacturing companies. In time however, the technology may become faster and cheaper for larger volumes, which could shift this balance. The pressure from actors upstream may keep prices of machines and raw material high initially, but as time passes this will probably become less of an issue, for example as new entrants increase competition. Legal aspects, high investment costs and liability issues make it difficult for customers to buy digital files and take over the manufacturing themselves. Some AM specialized actors may try to take market shares for spare parts or highly customizable parts though, so manufacturers may need some specific AM knowledge to protect these business areas if they are of high importance to the company.

For Alfa Laval, the results could be used as a basis for decisions regarding how AM could be utilized and add value within their business. As the company is old, well established and in a strong position in all their key technologies, there may be some resistance to take large risks. Investing in AM may involve some level of risk, although ignoring the emergence of this manufacturing technology could pose even greater risks as AL could fall behind in technical competence and miss out on upcoming opportunities and revenue. As they are a large corporation, financial aspects are not a huge issue, and it could therefore be desirable to try out different utilizations of AM before deciding which path to fully follow through. However, aiming to implement it incrementally may be the safest way to progress.

For other actors, the results prove that AM is still an emerging technology with a lot to be discovered, determined, and standardized. The thesis provides an overview of the emergence of AM technology from a business perspective. Companies interested in AM could benefit from the thesis results by receiving knowledge on whether the technology would be appropriate for their business or not. Supporting companies, for example working with software, logistics or post-processing, could use the results to find new business opportunities related to AM. Some of these might be more of a predictive nature, while others are lifted by current problems surrounding AM. Additionally, people and organizations who are involved in legal aspects will be given more background to why standardization and legislation is needed for AM.

7.3 Evaluation of process

The overarching methodology for this thesis was to use the double diamond model. This was conducted by first gaining data and deeper knowledge from literature and case studies, followed by a business model innovation process for an implementation of additive manufacturing at Alfa Laval. Throughout the entire process, useful input was received from several stakeholders. Finally, the feedback was connected to different criteria, see Table 8.1, together with findings in relevant literature to evaluate the results.

Since the thesis conducts a case study, mostly built on qualitative data, *the generalizability* of the results is limited. In section 8.3, the conclusions that other actors may draw from the results are discussed, but the most prominent conclusions are for AL, since the case study was conducted with them and the BMI therefore was applied to their specific situation. However, the conclusions for AL could be altered for similar business situations. Especially other global manufacturing firms could gain inspiration from some of the findings of this report. Additionally, the results that are not connected specifically to AL are more suitable for generalization.

The reliability of the data gathering can be seen as sufficient, regarding the literature study. In the screening process, 113 articles were looked into, and 67 were used and quoted in the report. This could be enough to eliminate most random variations, thereby ensuring reliability. However, for the case study, 17 people were interviewed for qualitative data. The received information was quality assured by confirming it with other people or in literature, and by interviewing people with different views and experience of AM, to avoid a biased perspective. The internal respondents were from several business units and had different roles within AL, while the external respondents were working in supplying companies or were researching AM in universities. Within AL, the first interviewees were found and approached purposefully, and these respondents gave implications on who to interview next based on who they thought could have more insight in the topics discussed in those interviews. This method in some ways increased the spread of respondents as people who otherwise would not have been thought of were contacted, at the same time as it limited the systematics of the interviews by not providing a selection that represented the entire organization. However, since the objective was to explore opportunities with AM, there was not an exact number of people or representative coverage needed in the sample. Furthermore, there were attempts of contacting customers to gain insights on their view of added value, although limited interest on AL's part made this a lesser priority. There were also discussions about interviewing designers, to get their opinions on switching to AM, which is a change that would have significant impact on parts of their work. Although, since the scope of this report limited the number of interviews, and the focus was more on strategical aspects rather than technical, they were not contacted.

The validity, that the intended subject of measurement was indeed what was measured, was ensured by continuous communication with LTH and AL. When focus changed during the process, the decision was taken in collaboration with these actors. Changes could occur when newly gathered information nudged the project towards new areas of interest, which was a conscious strategic decision that moved the project forward in a flexible way. Changes could also be requested by AL; either from our co-supervisor, the AM team or different people that were interviewed. By having a transparent and iterative process, the thesis project strived to generate value to both the academia and AL, to guarantee a capable master thesis and provide value to the client.

8 Conclusion & Implications

In this section, the conclusion is presented together with some final implications for the academia and Alfa Laval. This includes answers to the research questions, as well as suggested further research.

8.1 Conclusion

The most pertinent finding from this thesis is that an implementation of additive manufacturing would have a large impact on internal and external processes of companies, as well as demand innovation in certain elements of the business model. Most critically, companies need to ensure knowledge building and process development, and design a value proposition that facilitate their specific needs and prerequisites. From a broader perspective, there is a lack of standards and regulations for regarding important aspects of AM, which may initially hinder the development and wider implementation of the technology. A company generally needs to adjust value creation, value proposition, value capture, and value delivery the most, while the impact on value communication is limited. Depending on the way AM is implemented and which items are selected as AM candidates, the business model needs to be designed accordingly. As a more resource efficient metal manufacturing method, AM may contribute especially to three of UN's goals for sustainable development; Industry, innovation and infrastructure (no. 9), Responsible consumption and production (no. 12), and Climate action (no. 13).

8.1.1 Effect on internal and external processes

The first research question was related to how AM could potentially affect companies' internal and external processes. The answer was found through analysis of the information provided in the literature study and the case study.

How will the implementation of additive manufacturing affect internal and external processes, for companies in the metal manufacturing industry?

The literature study showed that an AM implementation could have significant impact on both internal and external processes of large manufacturing companies. Internal processes may be focused initially on education regarding AM. This includes knowledge in manufacturing, DfAM, and post-processing needs. As several respondents in the case study emphasized; knowledge building at each distribution center where AM is to be used is crucial. Additionally, since production and logistics of parts may shift, processes need to be developed to support this. Firms need to develop software and internal processes for order handling, in addition to finding ways to implement item selection processes for the evaluation of AM candidates.

Externally, the supply chain is expected to be affected substantially, as AM may reduce the number of suppliers of subcomponents, while the need for other suppliers may arise in their place. This includes suppliers of metal powder, printing machines, and actors performing post-processing. Logistical operations may also be disrupted due to changes in printing locations, with production moving closer to the customers. This could improve customer relationships and intensify collaborations with them. However, as IP gets increasingly difficult to protect, the risk of losing revenue due to competitors' copies arises. Thus, firms need to analyze the opportunities available for them specifically, in regard to their dynamic capabilities and specific assets, while at the same time mitigating involved risks and keeping track of other actors; both in their supply chain and surrounding it.

8.1.2 New business model

The second question was to find out how the business model could be innovated, which was investigated in both the literature study and the case study. Finally, this was applied to Alfa Laval in sections 5 and 6, using the 4I framework for business model innovation.

How can a manufacturing company's business model be innovated to support an implementation of additive manufacturing?

Most of the building blocks in companies' business models would be affected by an implementation of AM, such as changes in value creation, as the production method would change. Changes would also occur within other aspects of value creation, like core competencies and key resources, as the need for knowledge in different aspects of the technology increases. The value proposition of manufacturing firms has potential to become more service-oriented instead of solely offering products, while focus could be on lowered environmental impact and shortened lead times, if using printing-on-demand. The product offering may in many aspects remain the same, although in some cases contain better, more sustainable products thanks to redesign for AM. Depending on the size and current business model of the company, the AM adaptation could demand prominent changes or just become a small addition.

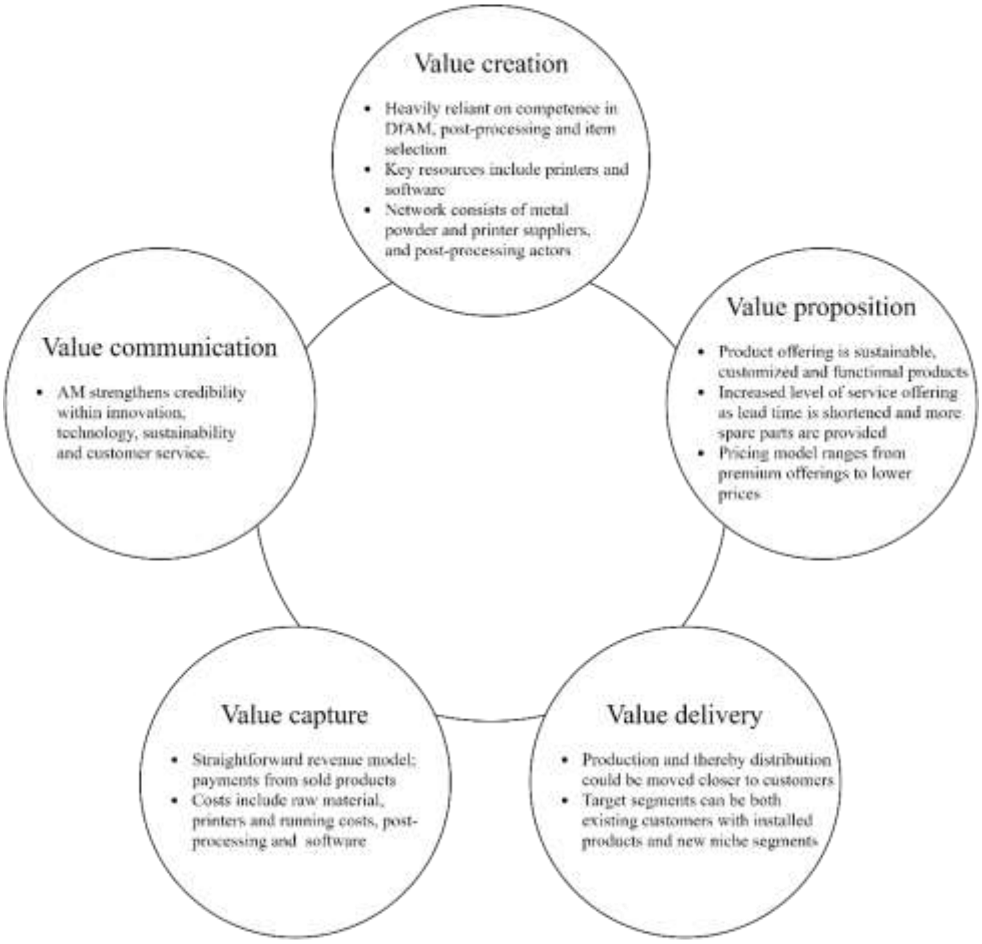

Figure 8.1 Business model for additive manufacturing, based on the framework by Rayna and Striukova (2016)

To respond to this research question specifically for Alfa Laval, the 360 ° business model framework was applied to the suggested implementation of AM. It is presented in Figure 8.1. There are some alterations made in most of the business model building blocks, although some goes through more thorough innovation. For AL, if they choose to implement AM for request items and research on new products, the impact is largely connected to the value creation, especially core competencies and key resources, due to investments in facilities and competence building. Furthermore, changes are made upon their value proposition; specifically, their product and service offering. The product offering most prominently shifts for new products that are redesigned for AM, into more sustainable products with higher quality, whereas the service offering mainly concerns the request items that will have shortened lead times and lowered environmental impact. Additionally, the value distribution could be moved closer to customers; improving customer relations and increasing collaboration.

8.1.3 Goals for sustainable development

An important aspect of the benefits with AM is the sustainability it can contribute to. To analyze this aspect, information on the subject was collected in the literature and case studies.

How can additive manufacturing be used to support the UN sustainability goals, specifically goal no. 9, no. 12, and no. 13?

An implementation of AM, specifically the chosen scenario and business model presented in this thesis, may contribute to three of UN's SDGs: Industry, innovation and infrastructure, Responsible consumption and production, and Climate action. AM has potential to encourage product redesign that may lead to more sustainable products and reduced waste of raw material. It could also decrease the climate footprint as the number and length of transports could be reduced. While AM is a process innovation in itself; it enables product innovation as design freedom is increased, in Alfa Laval's case specifically for new products.

Each of the SDGs have a number of targets and indicators that represent more specific objectives to fulfill. For example, goal no. 9, includes target 9.5, "*Enhance scientific research, upgrade the technological capabilities of industrial sectors in all countries, in particular developing countries (…)"* (United Nations, 2021b). AM could contribute to this target by increasing technological capabilities within AL as an industrial actor, and as AM is a novel technology and a process innovation itself, it also facilitates product innovation. The suggested implementation presented in this report advocates globally distributed production, which in long-term could increase innovation in developing countries as personnel at each DC needs to be educated within necessary processes related to AM.

AM strengthens responsible production as it in many cases is more resource efficient as a manufacturing method, compared to CM. Additionally, AM could drive circular economy. That way, AM contributes to target 12.2, "*By 2030, achieve the sustainable management and efficient use of natural resources*", and target 12.5, "*By 2030, substantially reduce waste generation through prevention, reduction, recycling and reuse*" (United Nations, 2021c) by decreasing the amount of metal powder and potentially using recycled material in production. Target 12.6, "*Encourage companies, especially large and transnational companies, to adopt sustainable practices and to integrate sustainability information into their reporting cycle*" (ibid), is something that the recommended implementation of AM would lead to within AL, and could possibly encourage other actors to follow the same path in the long run.

The implementation of AM, as suggested in this report, has the largest impact on sustainable development due to its reduction of greenhouse gas emissions. Thanks to globally distributed manufacturing, transports are reduced, leading to a lowered climate impact. The SDG that corresponds to this issue, no. 13, most prominently has political targets, though. The goal is aimed at taking climate action by for example regulating emissions of greenhouse gases, but the targets are specifically aimed at including combating climate change in national policies. For example, target 13.2 is to "*Integrate climate change measures into national policies, strategies and planning*" (United Nations, 2021d). The other targets relate to increase resilience in regard to climate hazards and raising awareness. Because of this, an implementation of AM is not directly contributing to the targets and indicators, although it can aid in the fulfillment of the general goal.

In the literature study, various conditions and trade-offs regarding AM and sustainability are presented, demonstrating that the environmental and climatic advantages only occur if certain measures are taken. As an example, reduced transports represent a positive consequence connected to an AM implementation, although it demands fewer transports from suppliers, for example through redesigned items with fewer subcomponents, and/or globally distributed manufacturing that prints the items closer to the customer. If AM is instead implemented at a centralized location, with not as strong a focus on product optimization; the reduction of climate emissions, connected to Climate action, SDG number 13, will not be as impactful. Therefore, the suggested implementation of spare parts distribution is aimed to be spread out globally, to strengthen the work towards lowered emissions of greenhouse gases through reduced or shortened transports.

Additionally, an implementation of AM could lead to obsolete machines staying in use for longer, since it enables production spare parts that would otherwise have been difficult to obtain. This is positive on one hand, as the lifecycle is prolonged and the need to procure a new machine is postponed. Although it could keep old machines, that are less resource efficient and emit more greenhouse gases, in use for a longer time even though there are better alternatives available. These types of trade-offs are important to consider for each decision that is made.

8.1.4 Alfa Laval's benefits

The fourth research question was regarding how Alfa Laval could profit from an AM implementation, which was answered by applying data from the literature study to the case study at AL.

How can Alfa Laval benefit from the value adding aspects of additive manufacturing?

Alfa Laval has three strategic goals, which are to improve their customer interaction, capitalize on their technology, and increase their service offering. AM could, if handled in an adequate way, align with all three of them. The technology could improve the customer interaction and service by increasing the amount of offered spare parts and lowering their lead times, at the same time as AL would place themselves at the forefront of technological development. An implementation of AM therefore contributes strongly to all three strategic goals.

Perhaps most critical, the scenario and business model were chosen and developed with the aim of adding value and generating revenue for AL. Some spare parts that otherwise could not have been manufactured or acquired can be produced and sold thanks to AM, thereby bringing previously lost revenue to AL. Research on new products could work as a complement, increase utilization of printers and add to their general sales. However, to ensure this progress and support future strategic decisions, continuous evaluation of the AM utilization and its business value is recommended.

Third, AL has a high ambition of fighting climate change, and has set the goal of carbon neutrality in 2030. To achieve this, AM could contribute significantly by increasing resource efficiency and moving production closer to the customer. As a result, globally distributed production could reduce flight transports; an activity contributing to high emissions for certain parts.

8.2 Implications for the academia

Further research is needed in several areas related to AM. As the technology is still emerging, more research could be conducted on the available opportunities for actors in other parts of the manufacturing supply chain. Business model innovation for AM could also be investigated deeper, for example in case studies of other firms with different roles. Customers, manufacturing firms, and suppliers may be able to use the technology in different ways to find new roles and positions. Additionally, supporting activities such as post-processing and software development for AM could be a growing market where the potential for new entrants might be significant.

Researchers could also investigate the most efficient ways of implementing AM, in regard to which activities to perform inhouse and which to outsource. The legal concerns, for instance regarding protection of IP, liability issues, international standards, and certifications are also fields of interest, in great need of further investigation to advance the utilization of AM.

8.3 Implications for Alfa Laval

This thesis provides an analysis of the current state of metal AM, in general and within Alfa Laval. Based on the literature and case study, a future scenario was created, specifying that AL has the opportunity to implement AM for production of request items and new products. A business model for AM was developed, specifically applied to AL's current situation and opportunities, and a step-by-step plan for this implementation was described. The findings of the thesis can be used as a basis for decision making, for the future of additive manufacturing at Alfa Laval.

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Appendix A – Interview data analysis

In this appendix, each Figure represents one of the 11 ***aggregate dimensions*** *from the interview analysis. These dimensions are seen to the right in each picture, when viewing the pages horizontally. To the left of these, in the middle of each Figure, the related* ***second order themes*** *are placed. Finally, the* ***first order concepts*** *are found to the left, grouped by which theme they compose.*

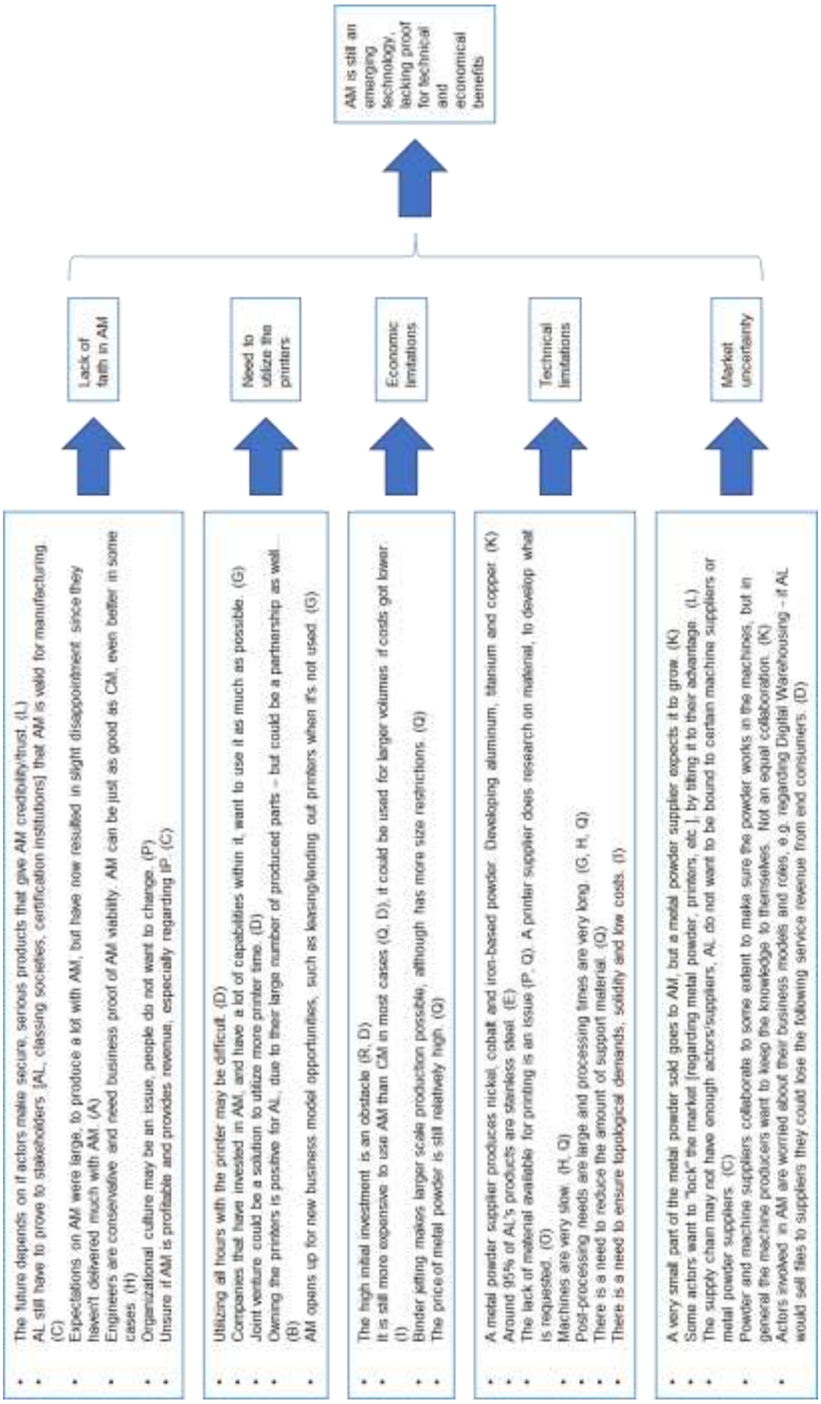

Figure A.1 AM is still an emerging technology

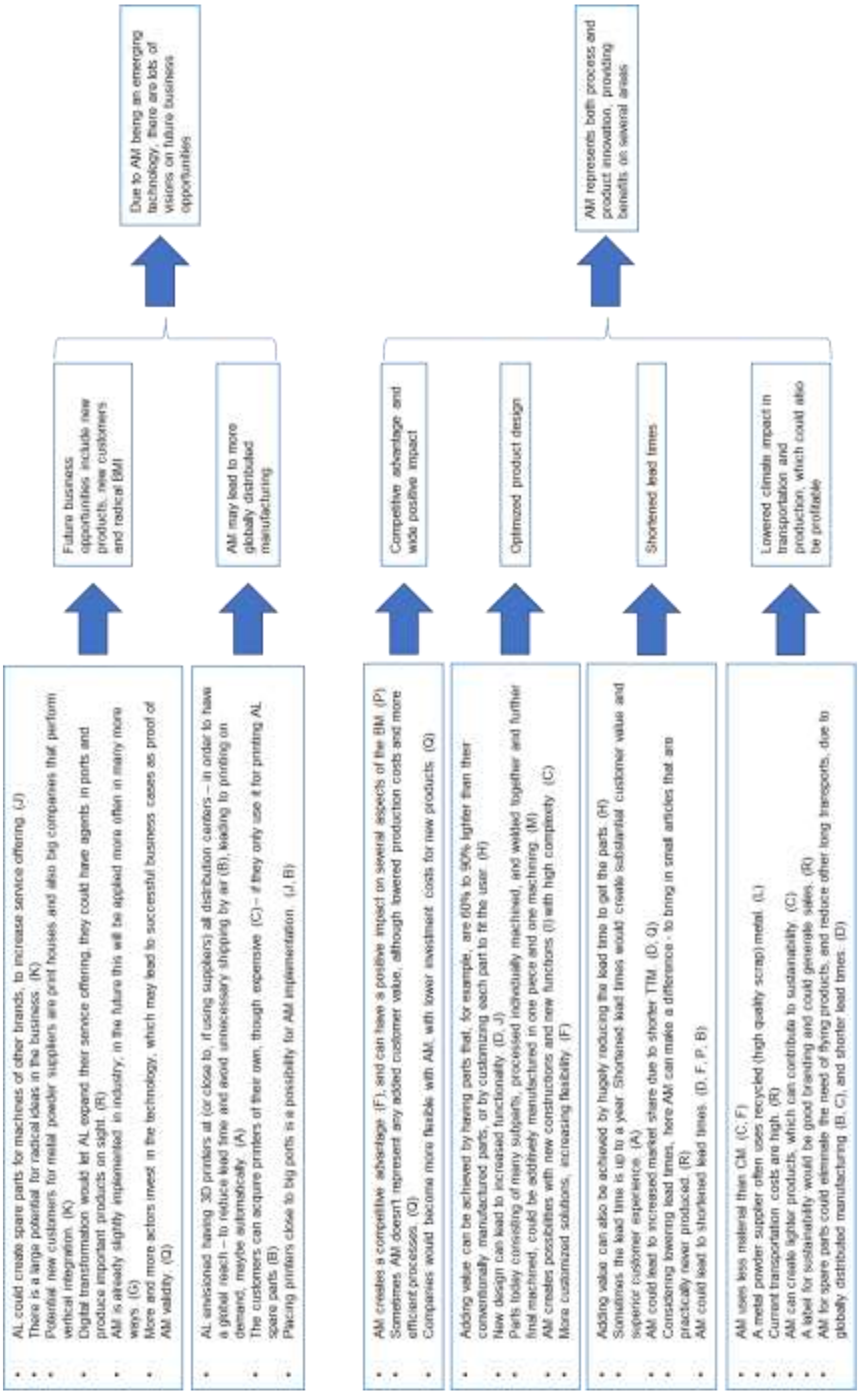

Figure A.2 (left) There are lots of visions on future business opportunities regarding AM
Figure A.3 (right) AM represents both process and product innovation

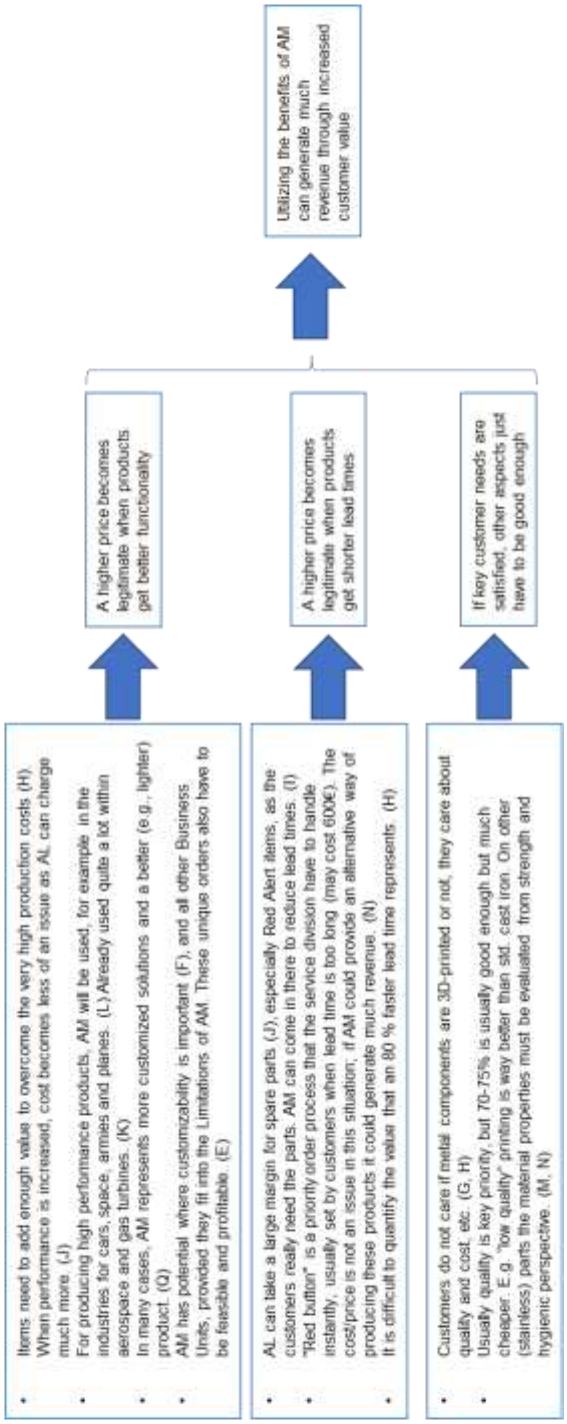

Figure A.4 Utilizing the benefits of AM can generate much customer value

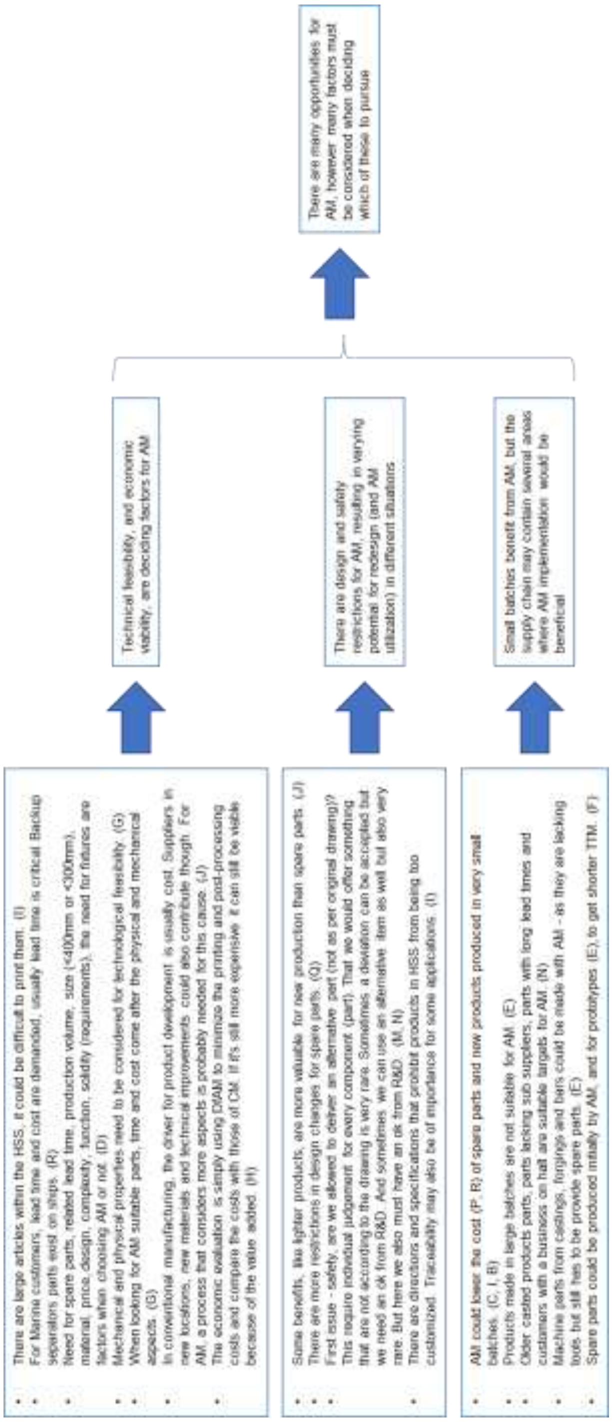

Figure A.5 There are many factors to consider for implementation of AM

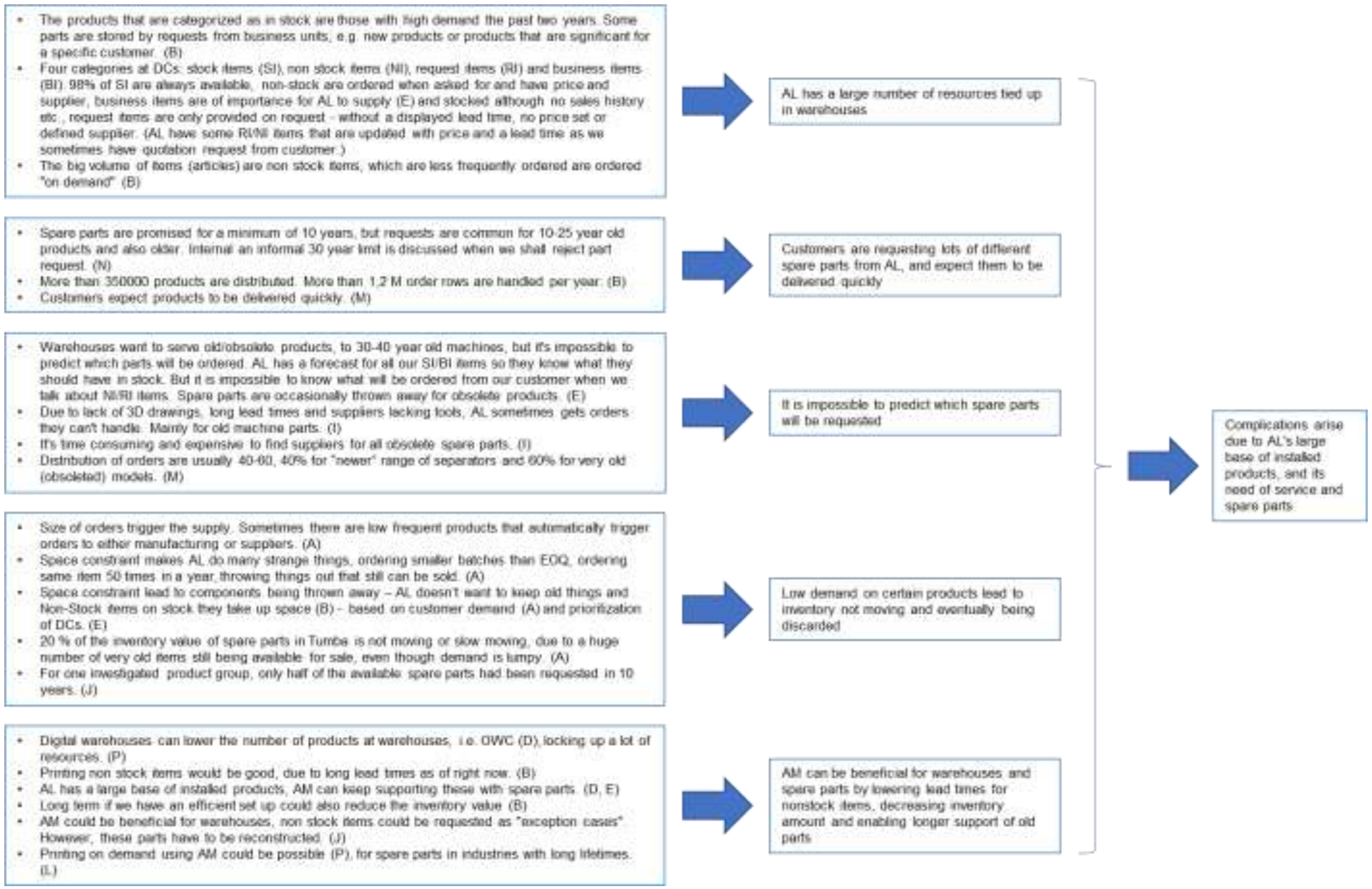

Figure A.6 AL and their large base of installed products

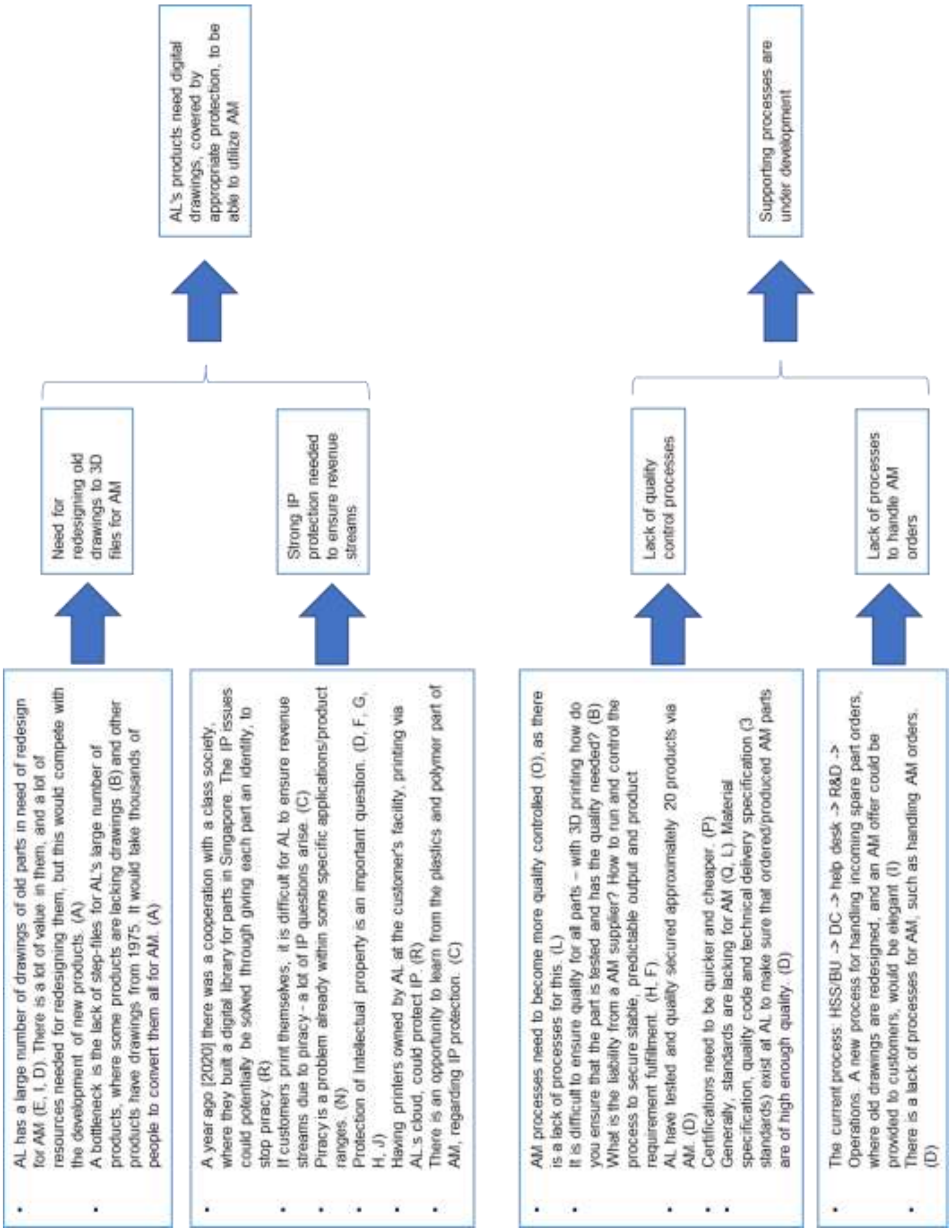

Figure A.7 (left) The need of digital drawings and appropriate protection for AM
Figure A.8 (right) Processes supporting AM are under development

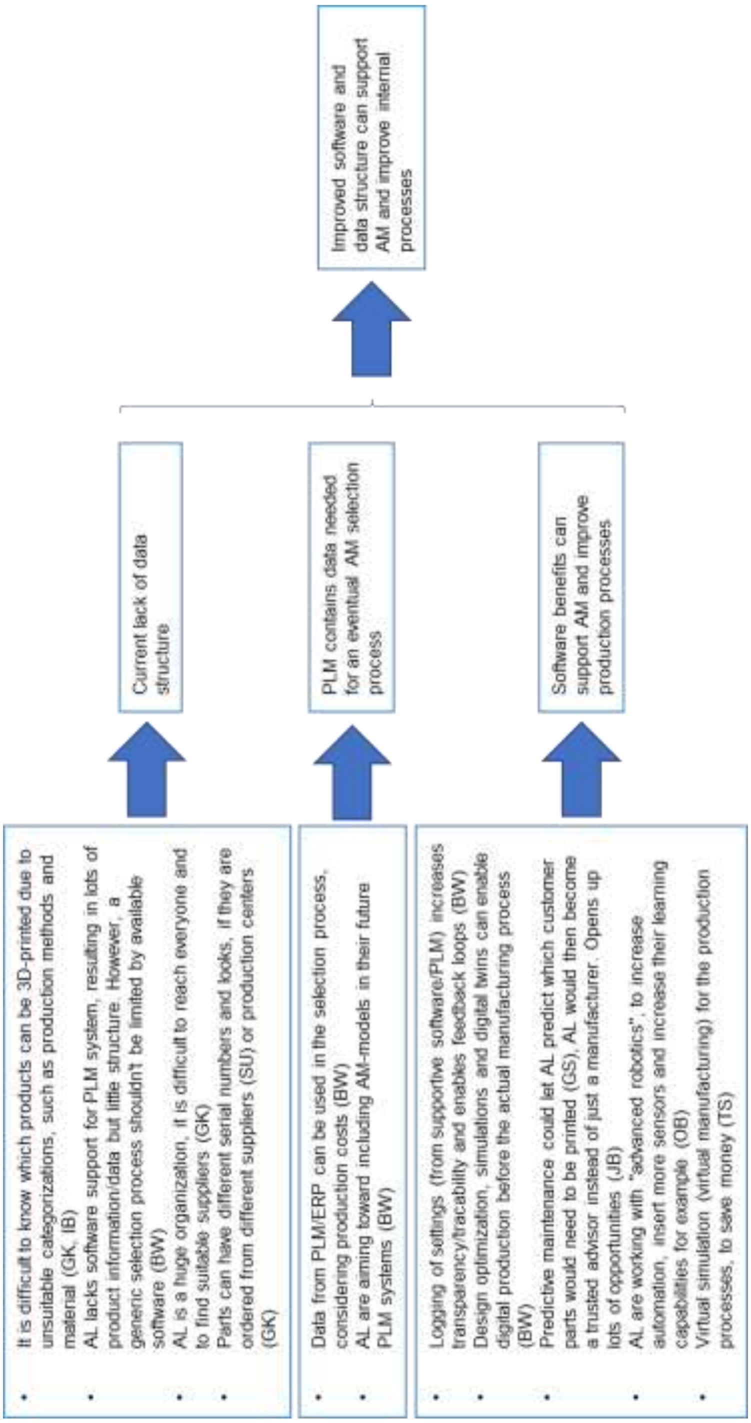

Figure A.9 Improved software and data structure can improve internal processes for AM

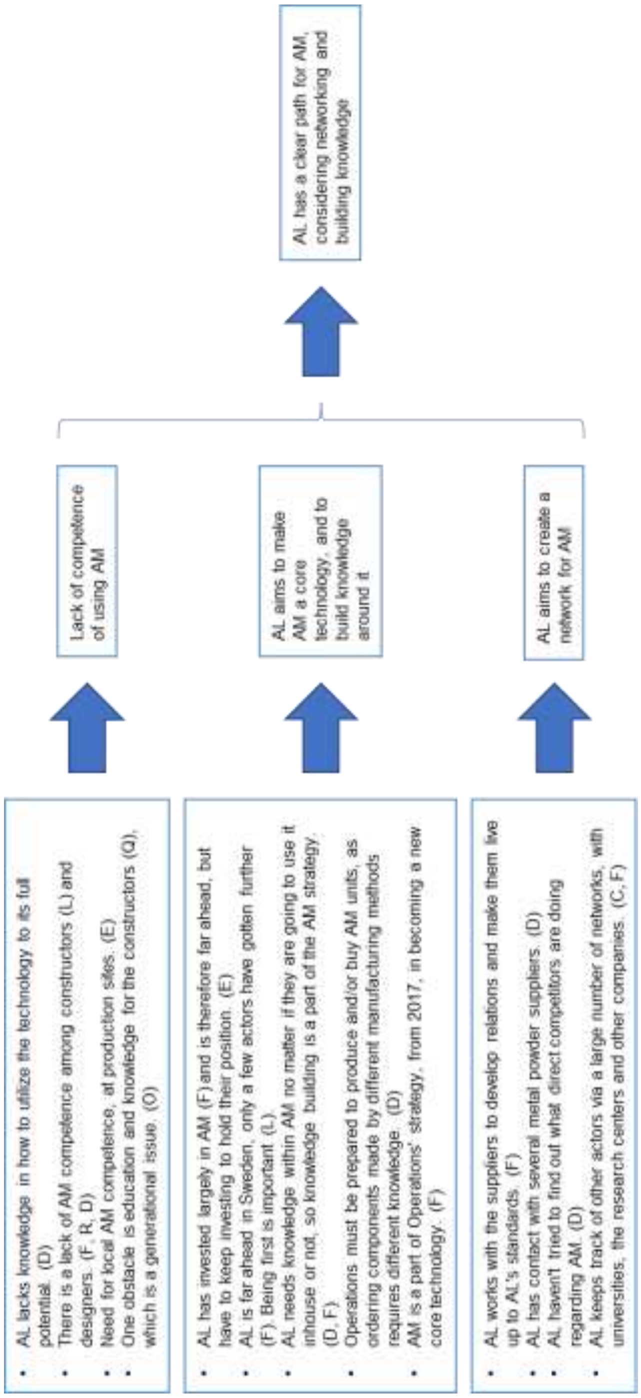

Figure A.10 Alfa Laval has a clear path for AM, considering networking and building knowledge

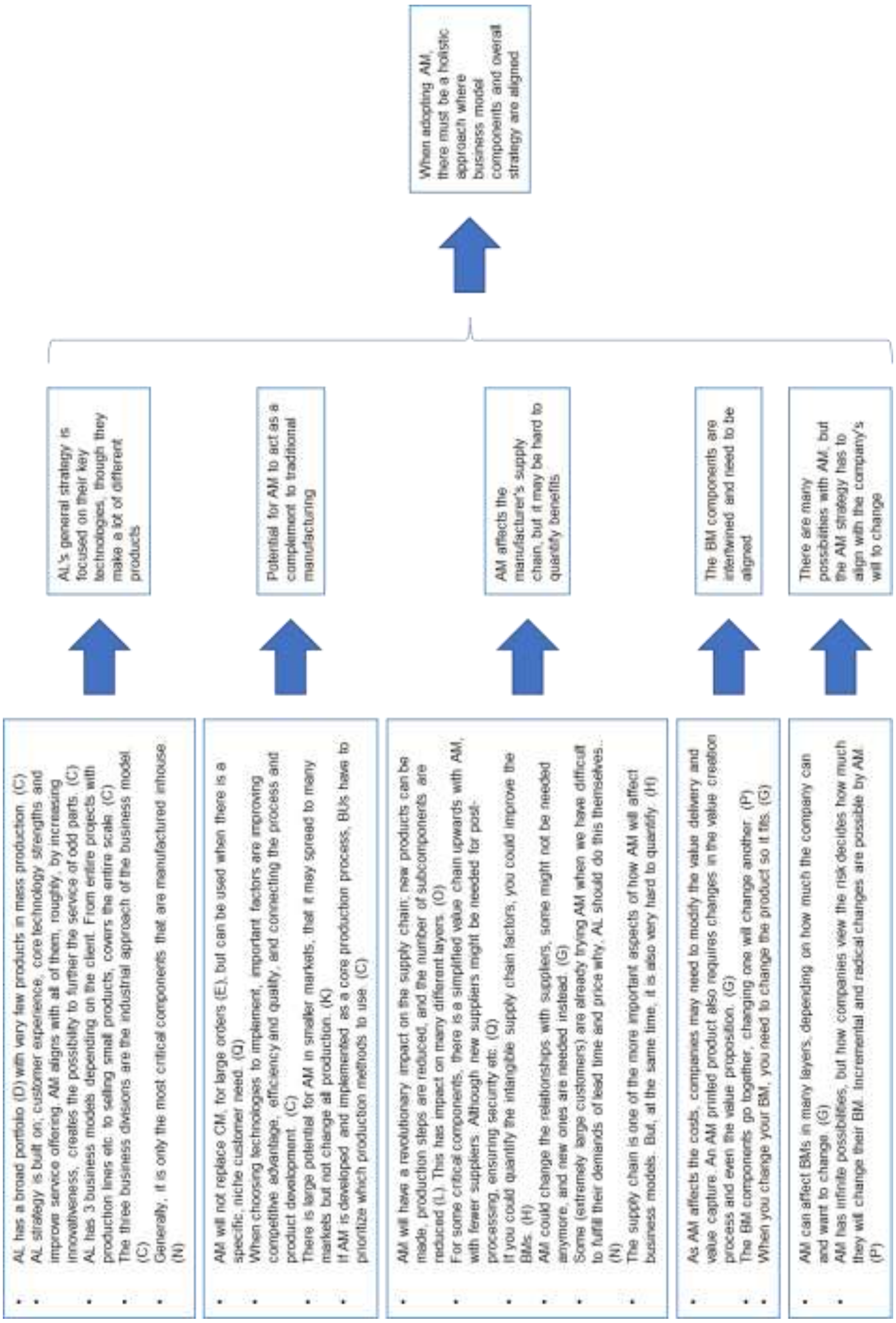

Figure A.11 There must be a holistic approach where the BM and overall strategy are aligned

Appendix B – Interview questions

In this appendix, an example of a semi structured interview is displayed. The questions varied depending on the respondent, as some were asked more about additive manufacturing and business models whereas interviews with people within Alfa Laval focused on their organisation and operations. All interviews included some questions regarding the future of additive manufacturing.

Additive manufacturing in an industrial context

- What is important when evaluating if a product is technically feasible to 3D-print?
- How do you evaluate if it is economically viable?
- Is it desirable from a customer perspective?
- Have you worked with, or researched, the implementation of AM in an industrial context? If so, please describe the process.
- What future scenarios do you think are plausible for manufacturing companies, in relation to metal AM?
- What challenges and obstacles do you see in relation to this?

Spare parts at Alfa Laval

- Are there any categorizations of spare parts, based on the following criteria:
    - Customizability
    - Complexity (subcomponents involved, or structure)
    - Demand, small or large batches
    - Average shelf time
    - Product location
    - Shipping location
- Are specific parts produced at one or several locations?
- Does it happen that spare parts are discarded for not being sold? To what extent?

Additive manufacturing at Alfa Laval

- Do you have any connection to the development and implementation of AM?

- Do you know how many of AL's products are technically possible to 3D-print?
- At the moment, does AL have a relationship with metal powder suppliers? In Sweden and in connection to distribution centers.
- What future scenarios do you think are plausible, in relation to AM?
- What challenges and obstacles do you see in relation to this?

Additive manufacturing and business models

- How do you think an implementation of AM would affect a company’s business model?
    - How will this affect the supply chain?
- Which aspects of the business model need to be innovated in response to AM?
- What are your thoughts on Digital warehouses? (Selling files that the customers can print themselves using other 3D-printers)
- Thoughts on other archetypes, e.g., subscriptions/insurance?
- When you implement a new business model, is there a certain process to follow?