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**INCENTIVES AND CHALLENGES FOR ADOPTING
ADDITIVE MANUFACTURING IN THE PLASTIC INDUSTRY**

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Acknowledgements

Abstract

Title	Incentives and challenges for adopting AM technology in the plastic industry
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Problem definition	Additive manufacturing is a technology that has received a lot of attention and many are wondering how it will affect them plastic industry in the future. Additive manufacturing is mostly used for prototyping today but there is reason to believe that the technology has potential to overtake other application areas for plastic or used as a complementary method to existing manufacturing technologies.
Purpose	The purpose of the thesis is to identify, describe and evaluate the incentives and challenges manufacturing companies in the plastic industry are facing when adopting AM-technologies.
Methodology	In this thesis the approach is going to be a combination of descriptive and exploratory together with deductive approach. The study is qualitative and based on gathered information from six interviews with plastic manufacturing companies, six qualitative surveys with people from the AM industry, complementary interviews and event participation. The empirics are summarized in Hill's manufacturing strategy and the results are analysed with the resistance model.
Conclusion	<p>The conclusion can be summarized in incentives and challenges for adopting additive manufacturing in the plastic industry.</p> <p>Incentives:</p> <ul style="list-style-type: none">• Can lead to shorter lead times• No tool investment for injection moulding• Ability to decentralize production• Reducing material waste• Possible to pursue mass customization <p>Challenges:</p> <ul style="list-style-type: none">• Long Cycle time• Size of build area and quality• Lacking design capabilities within plastic manufacturing companies

- Material shortage for AM
- Fragmented application areas for AM
- Lacking of experience of which products that are suitable to produce with AM
- Repeatability
- Reparability and atomization of machines

Key Words

Additive manufacturing, incentives, challenges, adoption, plastic industry, technology diffusion.

List of Acronyms

AM	Additive manufacturing
R&D	Research and development
SLA	Stereolithography
FDM	Fused deposition modelling
SLS	Selective laser sintering
3DP	Three dimensional printing

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1 Background and Problem Discussion

In the first chapter the background of this thesis is presented with a brief history of AM and the recent development of the technology. The subject is problematized and put in a larger perspective by describing the role of AM in the manufacturing industry. The purpose of the thesis is presented and the delimitations.

1.1 Introduction to additive manufacturing

In the history of industrial production there have been a few breakthroughs that have led to radical increases in productivity. The first breakthrough that started the industrial revolution was the invention of the steam engine. The second big leap was when the factories were electrified in the early 20th century, which transformed production from mostly small batch make to order production to mass production of standardized products. (Benhabib, 2003) The third big step was the automation of factories in the 1970s which replaced a lot of the low-skilled labour with machines. Since then it has only been incremental changes in manufacturing but with the breakthroughs that have happened in information technology and communications there is reason to believe that a fourth breakthrough will come in the near future. (Boston Consulting Group, 2015)

3D-printing (3DP) or additive manufacturing (AM) is one of the nine technologies that are going to transform production systems in a radical way (Boston Consulting Group, 2015). This transformation is called "Industry 4.0" and today there is a lot of research going on in the academic world and a lot of expectations from the industry and governments on the implications of this transformation. Apart from AM the other technologies are autonomous robots, simulation, horizontal and vertical system integration, the industrial internet of things, cyber security, the cloud, augmented reality, big data and analytics. These technologies are expected to make manufacturing more flexible and one of the most important things that will be different is the interaction between humans and machines. Information technology will be integrated through the whole value chain and will enable a greater automation. AM technology will be used in these production systems to produce small batches of customized products with construction advantages as complex geometries and lightweight constructions. AM systems will be able to reduce stock on hand levels and transportation time for these type of products. (Boston Consulting Group, 2015) Applications like producing spare parts, low volume/high value products and consumer 3DP are expected to change the supply chains of companies in a disruptive way by decentralizing production.

The technology behind the 3DP/AM was already invented in the 60's when the first attempts of solidifying liquid photopolymers took place. In the 70's the technology started to evolve and the number of patents of different techniques increased. It continued in the same pace in the first half of the 80's and in 1987 the company 3D systems Inc. commercialized the first AM system, which used the technology of stereolithography (SLA). In the 90's other

techniques where commercialized, selective laser sintering (SLS) and fused deposition modelling (FDM) being two of them. These three methods are still today the most common in AM with polymer materials. (Wohlers & Gornet, 2012)

The recent years the technology has evolved quickly. The number of patents in AM have increased and the number of companies in the market have also increased but the market is still dominated by a few large companies. Stratasys and 3D systems Inc. are the two largest companies delivering both equipment and materials and they have been around for a long time (Wohlers & Gornet, 2012) .They also hold the largest numbers of patents followed by Massachusetts institute of technology and Hewlett Packard. The market is currently in a growth stage and the numbers of companies are increasing (Gridlogics Technologies, 2014).

This change in the market has been driven by the technological progress that has lowered the costs of the products, which also has made it possible to commercialize products for the consumer market. The competitive advantage of AM compared to conventional manufacturing is the flexibility and the cost of producing high value products in a low volume. The applications of AM have therefore been in high value industries with low series like aerospace, jewellery and biological tissue (Gridlogics Technologies, 2014).Another application is rapid prototyping, which has also been common in all types of manufacturing companies.

For the applications mentioned above the technology is relatively well established. The largest application area for AM-technology is currently rapid prototyping. Because of the market development and increasing competition, prices for printers and material will decrease and therefore AM will also be more competitive as a regular manufacturing process. The technology is interesting for manufacturers that produce low to medium volumes of plastic details with high customization and high design complexity. Additive manufacturing is also believed to be able to change the supply chains by reduce transportation, lead times and inventory by on demand production. (Huang, Liu, Mokasdar, & Hou, 2012)

With the advantages that AM has towards its competing manufacturing processes and the increasing performance in mechanical properties and cycle time there is potential in some applications both in the industry and for the consumer market.

The hype around AM and the expectations of the effects in manufacturing have been high. For example, in Pwc's innovation survey, 63% of the informants thought that it was moderately to very likely that 3D-printing would be adopted by more than 50% of US manufacturers during the next 3-5 years. (Pwc, 2014)

Gartner's hype cycle for emerging technologies is a report made by the research and advisory company Gartner Inc. evaluating emerging technologies. The model shows where in the cycle the different technologies are and how long it will take for the technology to reach maturity. For 3DP/AM applications in enterprises the technology is in the stage "Slope of enlightenment" and is expected to reach the "Plateau of productivity" within 2-5 years from

now. Consumer 3DP is behind in the stage "Through of disillusionment" and is expected to reach maturity in 5-10 years. This shows a greater uncertainty in the segment of consumer 3DP. (Gartner Inc., 2015)

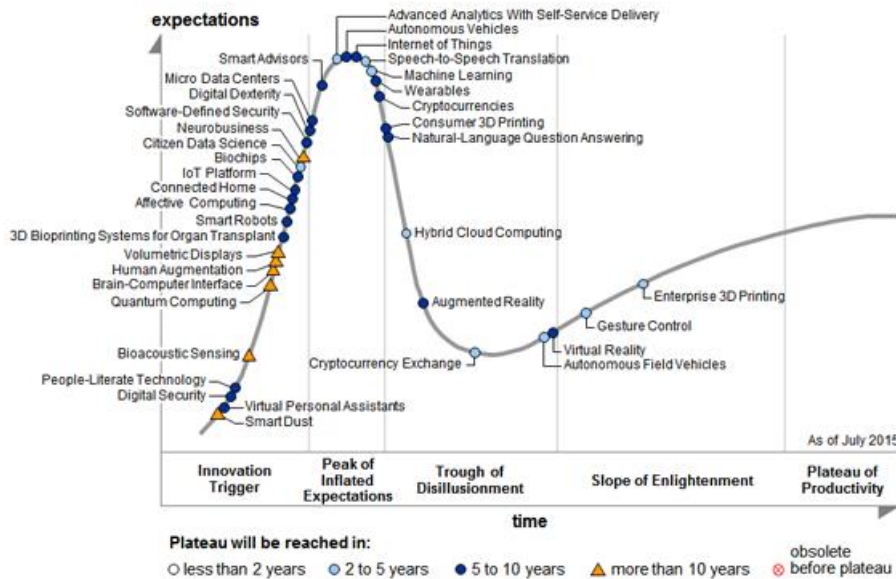


Figure 1-1.1 Gartner Hype cycle. (Gartner Inc., 2015)

Enterprise AM is reaching maturity and the technology should have the potential to be adopted on a broad scale in the manufacturing industry. There is a number of factors that affect the adoption of a new technology. It is not uncomplicated for a current manufacturer that for example uses injection moulding to adopt AM. These obstacles and challenges that the manufacturers face in the decision process to start using AM is the key to understand how the technology will be adopted. What are these factors and how are they going to affect the rate and character of the adoption of AM in the manufacturing industry?

1.2 Purpose

The purpose of the thesis is to identify, describe and evaluate the incentives and challenges manufacturing companies in the plastic industry are facing when adopting AM-technologies.

1.3 Delimitations

The target group of companies are Swedish manufacturing companies that uses injection moulding for making plastic products in-house. The company should have an interest in implementing AM or are already using AM for some applications.

1.4 Target audience

The target audience for this thesis is mainly two groups of people; students and researchers and actors within the industry.

Students and researchers within the fields of manufacturing strategy, design and innovation. This thesis touches a lot of different research areas and it investigates what the challenges and opportunities there are in integrating AM in manufacturing companies. The technology could potentially have a large impact on the manufacturing industry and this thesis gives a picture of what aspects will affect the development. One of the areas that will be affected is the design and construction of products. With AM, designers get a much greater level of freedom because they do not have to consider manufacturability. Innovation researchers are also a target audience because the subject is about what aspects that are effecting the diffusion of a new technology.

Actors within the industry is the second group that this thesis addresses. These actors can be companies that could benefit from adopting AM or companies that could enter the AM market and get a share in a growing market. This thesis gives them an overview of the possibilities and the challenges that the industry is facing.

1.5 Outline of the thesis

Chapter 1: Introduction

In the first chapter the background of this thesis is presented with a brief history of AM and the recent development of the technology. The subject is problematized and put in a larger perspective by describing the role of AM in the manufacturing industry. The purpose of the thesis is presented and the delimitations.

Chapter 2: Methodology

In the second chapter the methodological choices and the academic considerations about how the study was going to be conducted are explained and argued. The research process is briefly presented and the different phases in the study are explained.

Chapter 3: Theoretical Framework

In the third chapter the theoretical framework that is used to gather and categorize the empirical data is explained and discussed. The first part of the chapter will describe relevant information about AM technology that will provide a knowledge base that is necessary to be able to find the incentives and challenges that the companies face if implementing the new technology. Therefore, information about the different AM processes' strengths and weaknesses along with the current technology, injection moulding, will be summarised in a technology audit.

Chapter 4: Empirics

In this fourth chapter the gathered information is summarized and presented. The first part of the chapter the information about the technology in general, the opportunities and constraints is presented. The second part of the chapter the cases are presented with Hill's framework for manufacturing strategy.

Chapter 5: Analysis

In the fifth chapter the gathered information from the interviews, the survey and the literature will be analysed to identify the incentives and challenges there are for companies within the plastic industry to adopt AM technology. The first part of the analysis will be about what incentives that can be identified in this study and in the second part the challenges will be identified using the resistance model created by MacVaugh and Schiavone.

Chapter 6: Summary and Conclusion

In the sixth chapter the most important points from the analysis is summarized and the implications of the results are elaborated with and put in a wider perspective.

Chapter 7: Reflection

The seventh chapter will discuss the structure for the working process of the master thesis. The companies involved will be discusses as well as other information sources. The challenges that have appeared will be evaluated and in what way they have had an effect on the produced results. Reflection concerning future research and contribution and general and academic contribution will also be included in this chapter.

2 Methodology

In the second chapter the methodological choices and the academic considerations about how the study was going to be conducted are explained and argued. The research process is briefly presented and the different phases in the study are explained.

2.1 Methodological approach

There are four possible alternatives to use when classifying the methodology approach for an academic study. The different approaches are descriptive, exploratory, explanatory and problem solving. A descriptive approach implies that the main purpose of the study is to understand and describe how something is functioning. In an exploratory approach the main purpose is instead to understand the underlying functions of the studied object. An explanatory approach is when the study aims to find causation and explanations. In a problem solving approach the objective is to find a solution to an identified problem. (Höst, Regnell, & Runesson, 2006)

In this study the approach is going to be a combination of descriptive and exploratory. To be able to analyse the incentives and challenges for companies in the target group it is necessary to have a descriptive approach to understand the internal organisation and the external environment. The descriptive part of the approach will also be used to describe the possible implications of adopting AM technology based on the current situation in the companies. When the situation in the companies are evaluated the objective is to find incentives and challenges in adopting AM-technology. For that objective a combination with an exploratory approach is used to go in depth to the specific aspects that is affected when switching to AM-technology. The exploratory approach is going to be used to find which incentives and challenges that are important for the adoption process. When the incentives and challenges are identified it is necessary to explore how the companies value these and how important the different aspects are.

2.1.1 Research logic – Deductive vs Inductive approach

In research there is also another perspective to the approach that can be chosen for a project. That perspective is about the logical approach the researcher has to the research. It is called logical reasoning and it can be divided into two approaches: deductive and inductive approaches. With a deductive approach the researcher investigates the problem through the lens provided by previous rules, research or theories. That represents a bottom down approach where the research should start with existing theory. The inductive approach on the other hand aims to produce new theories and knowledge in an area where the previous research is limited. That represents a bottom up approach where the research should end up with new theory. In addition to these two approaches a combination called abductive approach can be used. (Kirkeby, 1994). This study takes a deductive approach and tries to gather information about and analyse the problem using models and theories in research areas such as operations management and innovation theory. These areas are well researched and will be combined to build a theoretical framework relevant to the research purpose.

2.2 Case study

Case study research is a research method that investigates a contemporary phenomenon within the natural context using multiple sources of evidence (Yin, 1984). It is a broad category of analysis and is used in many different disciplines. The case study focuses on an individual representative of a group, an organisation or organisations, or a phenomenon. Another characteristic of the case study is that the phenomenon is studied in the natural context. (Hancock & Algozzine, 2011) A case study is also appropriate for the purpose of this thesis because of the necessity of having a holistic view of the studied processes. (Denscombe, 2000)

An advantage with a case study is that it is possible to use multiple research methods and multiple data sources. This case study is about the complex processes in the external environment of the company so the approach for using data sources and research methods is going to be pragmatic to best suit the purpose. In a case study the three most common methods of primary data collection are interviews, observations and archive analysis. (Descombe, M. 2000)

2.3 Case study design

According to Yin, the case study design of a study is supposed to work like an action plan to get from the initial research questions to the conclusions about those research questions. The design is how to conduct the case research to get to the right conclusions. For case studies, five components are important to acknowledge. (Yin, 1984)

1. A study's questions
2. Its propositions if any
3. Its unit(s) of analysis
4. The logic linking the data to the propositions
5. The criteria for interpreting the findings

In this case study the question is what the incentives and challenges there are in the plastic manufacturing industry to adopt AM technology. This study has a combination of descriptive and exploratory approach where the goal is to find something that is not defined before the study begins. With an exploratory approach there is reason for not having any propositions because the whole point of an exploratory study is that the researchers do not know before the study what will be found. The unit of analysis in this study is the event of the adoption process of AM technology within the plastic manufacturing industry. That is what the study is aiming on analysing. However, the gathered data is going to come from several companies in the manufacturing industry and other stakeholders in the AM industry. The information from these sources is going to be interpreted by what technological limitations and opportunities the technology has and also what advantages and challenges companies might face internally when adopting the technology. (Yin, 1984)

In case study research there are different types of designs that are appropriate for different types of research problems. These designs can be classified as intrinsic, instrumental or collective. Intrinsic research is appropriate when the researcher wants to know more about a particular individual, group, event or organization and when the researcher is not trying to create new theory or generalizing their findings to a broader population. Instrumental design is used when the researcher wants to better understand a theoretical question or problem. With an instrumental design the understanding of the particular issue that is being examined is of secondary importance and the insights about the theoretical explanation of the issue is of primary importance. Collective case study attempts to address an issue while also adding to the literature base that helps us better conceptualize a theory. When using this design, the study often contains several instrumental case studies to enhance the ability to theorize about a larger collection of cases. (Hancock & Algozzine, 2011)

In this study the design is going to be an intrinsic multi-case study. According to Yin the evidence from a multiple-case study is often more compelling and the overall study is therefore regarded as more robust (Yin, 1984). The purpose of doing a multiple case study in this case is to be able to investigate different companies that have different strategies, resources and organizations. The differences and similarities will be analysed and patterns will highlight where there might be consensus in the industry and where there is no consensus. The multi-case design is therefore appropriate to be able to draw conclusions about the group that this study is focusing on. In addition to the cases there will be information gathered from sources outside of the focus group of the thesis to get knowledge useful to understand the underlying mechanisms of the development and to get information from other sources that have a different perspective. Therefore, this study also benefits from having an intrinsic design to investigate the event of the innovation diffusion of AM technology.

2.4 Qualitative or quantitative research approaches

In research there is a distinction between qualitative and quantitative methods. According to Hancock and Algozzine (2011) the decision to use a qualitative or a quantitative approach is largely dependent on the goals and the preferences of the researcher. If time and resources is limited a quantitative research method might be more appropriate because the researcher, then can use already existing statistics or conduct tests and surveys that measure some variables. (Hancock & Algozzine, 2011) These methods produce statistical data that represent for example opinions of a large group of people, which can be useful for some purposes. For other purposes it may be more useful to use a qualitative approach where the researcher use interviews, focus groups, observations, a review of existing documents or a combination of data collection procedures (Hancock and Algozzine, 2011).

If the knowledge of a subject is low, it might be beneficial to use a qualitative approach because it allows the researcher to explore how many factors influence a situation. In the diffusion process of a new technology there is a lot of different factors that affect the rate of adoption or the rejection of an innovation. Therefore, it is more appropriate to use a

qualitative method to be able to explore which factors are the most influential in how the diffusion process is going to evolve. According to Hancock and Algozzine (2011) the relationship of the researcher to those being studied is also a factor affecting the decision of using a qualitative or quantitative approach. In qualitative research, the goal is to understand the situation under investigation of primarily from the participants' perspective (Hancock & Algozzine, 2011). This is called the insiders perspective or the emic perspective as opposed to the etic or the outsider's perspective. In this study the insider perspective will be more useful to be able to understand the incentives and challenges for them to adopt AM technology.

2.5 Information gathering – Qualitative interviews

Interviews is a very common method of collecting data because it is a good way of collecting qualitative and personalized information and important insights about the issue. There are a few things that has to be considered when using interviews as a data collection method. A key problem with interviews is to get participants that are relevant and have the right knowledge about the subject. Therefore, it is important to structure the process finding and selecting the participants. (Hancock & Algozzine, 2011)

The next step is to construct an interview guide that is going to be used in the interviews. It will contain some open ended questions that will be asked every interviewee and makes sure that it gives the insights and information that is needed for the research questions. (Hancock & Algozzine, 2011) The number of questions vary a lot depending on the research questions. In this study the important thing is to construct the interview guide so that every interviewee gives information needed to use the models in the theoretical framework.

Other aspects that has to be considered are the setting in which the interviews are held, recording of the interviews and legal and ethical aspects. The setting in which the interviews are going to be held in this study is going to be at the companies which participates. The reason for that is partly the convenience for the participants and that the interviewees are going to be more comfortable in their own regular workplace. It is also good to visit the company to get a chance to see the production site, which might give information that otherwise would be missed. The interviews are going to be recorded and transcribed in a written document. (Hancock & Algozzine, 2011)

Interviews can be structured, semi structured or unstructured. In structured interviews the interviewee is asked questions that are predetermined word for word. It is more like a survey questionnaire but with the interviewee giving the answers verbally. In unstructured and semi-structured interviews there is a questionnaire that is prepared before the interview but there is room for improvisation. The researchers also have more freedom to ask follow up questions and adapting to the interviewee. (Myers & Newman, 2007) Semi structured interviews are especially well suited for case study research (Hancock & Algozzine, 2011).

When choosing to conduct quantitative interviews the interviewer should be aware of the difficulties and problems that can occur. This problems or pitfalls should be avoided to

increase the potential of making professional and holistic interviews. One of the problems that might occur is called Artificiality of the interview. This problem is that the interviewed object might get the feeling of being interrogated when creating opinions to a complete stranger under time pressure. There can also be a lack of trust due to the unknown interviewer and the person might be hesitant to share what could be sensitive information during the interview. This could lead to insufficient information gathering for the purpose of the interview. Another aspect that can lead to insufficient data is the lack of time. This can also be linked the artificiality of the interview where the interviewed object may feel forced to create opinions under time pressure which can lead to unreliable information. Another pitfall could be the level of entry. If the interviewer is considered to have a lower level position than the potential interviewee, it could be difficult to realize an interview with this person. This may also restrict the variation of data that can be gathered when not accessing the appropriate interviewee. (Myers & Newman, 2007)

In this study the interviews are going to be semi structured with a pre-determined questionnaire that has a number of open questions that should cover the topics that is needed for the analysis but also have room for follow up questions and discussing topics that the interviewee thinks are especially important.

2.6 Information gathering – Qualitative survey

In addition to the qualitative interviews in the case studies, a survey was conducted to get qualitative information about the opportunities and constraints with the technology. The purpose of the survey was to ask experts in the field of AM a few open questions where they would reason freely and discuss their views and analysis of the future of AM. This would provide information from the perspective of the stakeholders of AM technology, which is the ones that work with the technology today. That information would be compared to the information from the case companies to see if there is consensus of what the constraints and opportunities are with the technology. The standard questionnaire for the qualitative survey is presented in appendix 2, which were modified a bit for every person depending on what role and what type of knowledge the person had.

Table 2-1: Summary of survey replies

Survey replies		
Organization	Informant	Date
PLM group	Tawfiq Shams	25th of April 2016
3dp.com	Mattias Kristiansson	26th of April 2016
Protech	Evald Ottosson	3d of May 2016
GT Prototyper	Mikael Sohlberg	4th of May 2016
Arrk europe LTD	Erik Bjälkvall	4th of May 2016
Addema	Samuel Löfstrand	11th of May 2016

In table 2-1, the people who answered the survey are presented with the date they answered the survey and the organization they represent.

2.7 Finding the interviewees

There are two main issues when trying to find the right participants for the interviews. The first issue is to find the right company that is relevant to the subject. The second is to find the right person in the company. The person must have a position that gives him experience and an insight of the asked questions. The questions will cover several parts of the company and it can be difficult to find a person that have knowledge about all of those issues. It can be necessary to interview several people at the same company and also complement the face to face interview with follow up questions via e-mail after.

To find the right company the following criterion were set up:

- Should sell plastic products
- Should have the production in house.
- Should use injection moulding.
- Should be active within the Swedish boarder.
- Should have economic/technological interest in AM technology.

To find the right person persons the following criterion were set up:

- Be familiar with AM technology.
- Have knowledge about how AM technology could be used in the company.

- Have knowledge about how AM technology affect the following functions and issues of the company:
 - Design and construction.
 - Operations and organization.
 - Corporate objectives and marketing strategy.
 - Manufacturing costs.
 - Manufacturing methods.
- Have knowledge about the company's future plans and challenges.

The first stage in the process of finding the right companies were to make a short list with possible companies. This short list consisted of companies from the web page industrtorget.se, which have an extensive list of industrial companies in Sweden. It has the possibility to search for companies in regards to certain criterion such as region, type of industry and manufacturing methods. The search criterion used were that the companies should be in the plastic industry and use injection moulding as manufacturing method. That resulted in a list of possible companies and from that list companies were swiftly reviewed and the ones that seemed most relevant in regards to the criterion above were put in the short list.

Another web page that were used when finding the right companies were plastportalen.se, which is a site made by Svensk Plastindustriförening, the Swedish plastic industry association. On that web page there was also a list of plastic companies that used injection moulding and that list were used in the same way as described above.

The next stage in getting participants were to e-mail the companies in the short list. The first e-mail was a standard message where the purpose of the thesis was explained and the reason for the interest in getting them to participate in the study. If the company where interested in participating the contact continued with a discussion about who in the company would be appropriate to interview. Often the company had a proposition, which led to further contact with the person in question. That person where asked questions to get an answer if all the criterion were fulfilled.

Table 2-2: Summary of interviewed case companies

Case companies		
Company	Interviewees	Date
Atos medical	Rickard Falkenberg	16th of March 2016
Nolato Meditech	Niklas Johansson and Ronny Bengtsson	7th of April 2016
Kanor Plast	Lars Nordström	18th of April 2016
Prototal PDS	Ola Anteryd and Christian Stadling	20th of April 2016
Frohe AB	Mårten Samuelsson	28th of April 2016
DETUS Formplast	Urban Tomaszewski	2nd of May 2016

In table 2-2, the interviewees are presented with the date the interview was made and the company that they represent.

2.8 Constructing the questionnaire

The questionnaire must be constructed so that it targets the information needed to perform an analysis with the theoretical framework described in chapter 3. The first part of the questionnaire is about assessing the current situation in the company/organisation. It will be questions about what they do, their business model, the processes etc. The purpose of this part in the questionnaire is to get information about the corporate objectives, market strategy, order winners/qualifiers, process choice and infrastructure for Hill's model. The second part is about getting information about which knowledge, attitudes and difficulties the company has for implementing 3D-printing in the production. The purpose of this part is to get information that will be used to evaluate the challenges and incentives for the companies to implement AM and to get information of how the Hill model would change with a different process choice. The last part of the interview is about materials. The purpose of that part is to investigate the material needs of the interviewee in terms of material choice, price, properties and what material development that would have potential in the future. When meeting different companies and organisations some of the questions will not be relevant. The best way of dealing with this problem is to have a pragmatic approach to the interviews and tailor the questionnaire to each interviewee. However, the questionnaire always had the same structure. The standard questionnaire is presented in appendix 1.

In the qualitative survey the same approach was taken as described above. A standard form of questions were made but some questions were modified to fit the informants background and knowledge.

2.8.1 Additional interviews

In addition to the primary interviews that are a part of the target group, other interviews were conducted to get information about AM technology in general and the development in the broader market. The purpose of those interviews were to build a knowledge base to better understand the context in which the target companies are active. The primary search on the internet resulted in a list of companies that use injection moulding in house and to complement this list there was also a search among larger companies that might have the production outsourced. Larger companies have a broader range of products and will most probably be affected by AM technology. Larger companies that outsource the manufacturing of plastic details will be influential because it is they who design the products and decide how they will be produced. They put a lot of resources into research and innovation and are opinion leaders that have an effect on the industry. In addition to that they also have direct power on their sub-contractors, which they can use to influence them to adopt new manufacturing technologies. Another aspect is that larger companies might have interest in the production of spare parts, which is one of the types of low volume manufacturing that is very beneficial with AM technology. Other people that can provide information and insights about the development in the AM industry is also interesting to interview for example people in the AM industry or from universities.

The interviews that were made face to face were recorded and transcribed into a document. The statements made by the interviewee were written down word for word to capture the exact formulations of the interviewees.

Table 2-3: Summary of additional interviews

Additional interviews		
Organization	Interviewee	Date
Lund university	Professor Olaf Diegel	24th February 2016
Tetra Pak	Lars Sickert	31th of March
Tetra Pak	Rickard Nilsson	27th of April 2016

Table 2-4: Summary of event participation

Event participation		
Hosting organisation	Event	Date
Easyfairs Scandinavia	Plastteknik nordic 2016	13th of April 2016
SWEREA	Open house in the lab	28th of April 2016

In table 2-3, the interviewees from the additional interviews are presented with the date the interview was made and the organization they represent. In table 2-4, the events that were visited are presented with the date and the hosting organisation.

2.9 Research process

The research process that is presented in 2-1, was created as an iterative and deductive process. At first it was important to understand the technology and how it can be used, its pros and cons, in what industries it can be adopted and how far the adoption process has come today. Therefore, the first stage consisted mostly of gathering information from secondary sources such as web sources, academic articles and consultancy reports. However primary sources were also used in this stage of the process. The additional interviews described in chapter 2.8.1 was also a part of this stage. The second stage was to create an appropriate theoretical framework that would be used to analyse the problem. That stage was about framing the problem and searching the literature for models and theory that would be useful. Literature fields like management theory, operations theory and innovation theory were the ones that were mostly examined. After the theoretical framework was established the next stage was about contacting potential participants for the study and to create the questionnaire. Next stage was to interview the participating companies and to document the findings. The last stages of the study were to analyse and compare the findings for the different participating companies and to produce conclusions from the analysis.

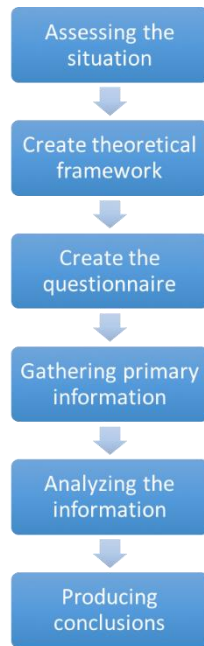


Figure 2-1: Research process

As the interviews provided new information and insights the questionnaire was adjusted during the interview process. The possibility of asking follow-up questions via e-mail was used to ask these questions to previous interviewees along the process.

2.10 Data credibility

In research the gathered primary information has to have a high credibility and that is dependent on the credibility of the methodology used to conduct the research. According to Raimond (1993) the evidence and the conclusions have to be tested with two different perspectives; reliability and validity. In this chapter the methodology of this thesis is discussed with regards to these two perspectives. (Raimond, 1993)

2.11 Quality of result

To measure the credibility of the results presented in this thesis, two parameters for measurement will be used which are the reliability and the validity.

2.11.1 Reliability

The objectives are to ensure that if repeating the process and following the same procedures when conducting the research, the findings and conclusions should be the same. By having a high reliability, errors and biases in the case study can be kept to a minimum. To enable other investigators to repeat to process, the procedures in the case study need to be well documented. (Yin, 1984)

To ensure reliability of the thesis, the process have been successively explained when gathering information and selecting sources. It is important to keep in mind that the conducted interviews and question forms has to an extent been customized for the interviewee and with semi structured interviews, parts are meant for open discussion and follow up questions. This means that if repeating the interviews, some answers can be different than the information gathered in this thesis. To minimize the risk of interpretation of information all of the interviews have been recorded and transcribed. The questionnaire for the interviews and surveys can be found in appendix 1 and 2.

Another aspect relating to the reliability is the process of choosing the companies. The qualitative insights coming from the companies that were willing to participate in the study may not be the same if other companies would have been chosen.

2.11.2 Validity

Validity is when ensuring that the findings in the study are generalizable for other case studies (Yin, 1984). This can be reached by making sure that the interviewees are not steered in a desired direction and not having leading questions. By structuring the interviews to have parts where the person has freedom to speak freely the validity of the study can be kept high.

Two kind of triangulation have been used to increase to validity of the study, methods triangulation and triangulation of sources. Methods triangulation is reached by having different sources of data collection methods to verify the consistency of the information. Triangulation of sources is when checking the consistency of the data gathered from different sources with the same method. The logic behind triangulation is while a method reveals one aspect for empirical reality, multiple methods of data collection provide more information and aspects for the research. (Patton, 1999). In this thesis the triangulation has been reached by using interviews and surveys to collect data and through using multiple sources for each method and checking the consistency.

3 Theory

In the third chapter the theoretical framework that is used to gather and categorize the empirical data is explained and discussed. The first part of the chapter will describe relevant information about AM technology that will provide a knowledge base that is necessary to be able to find the incentives and challenges that the companies face if implementing the new technology. Therefore, information about the different AM processes' strengths and weaknesses along with the current technology, injection moulding, will be summarised in a technology audit.

Hill's framework for manufacturing strategy is used to gather and categorizing information from the interviews with the case companies. This is because it focuses on the strategic areas of a manufacturing company and connects it to the process choice, which is the focus in this study. By applying Hill's models, information regarding the companies' thoughts on where AM technology fits in their company model can be gathered. In addition to the information that is needed in the model, information about the incentives and challenges in the individual companies are going to extend the model to see how they affect the manufacturing strategy.

Drawing conclusions about the gathered data from the technology audit and the case companies requires a model that takes a lot of different factors into consideration, both factors about the advantages and challenges with the technology, factors about the difficulties individual manufacturing companies face and factors that affect the industry in general. For this purpose, general theory of diffusion of innovations are presented to understand the underlying mechanisms of technology diffusion, which is the theory behind the resistance model by MacVaugh and Schiavone. The resistance model will be used to analyse the gathered data and evaluating how strong the resistance factors. The model takes a multidisciplinary approach that uses theories in the fields of sociology, marketing, research and development and diffusion theory. The model takes a broad approach and looks at the social systems that the individual is a part of. It also analyses how the technology is affecting and is affected by factors in the larger economic perspective.

3.1 Technology audit

To be able to understand the incentives, challenges and strategic choices the case companies face if adopting AM technology, a broad overview of the technology is needed. The chapter is called a technology audit and it will contain a brief explanation of how the different AM processes work and how the contesting technology injection moulding works. It will also have a section containing gathered information from literature, interviews and the survey about the technological advantages and limitations and the market opportunities and constraints. It is similar to a SWOT analysis but is used only as a way of presenting information and inspired by the way Baumers presents generic benefits and limitations of AM technology on the firm level and at in larger economic system. (Baumers, Dickens, Tuck, & Hague, 2016)

3.2 Terry Hill Manufacturing strategy

Terry Hill's framework for manufacturing strategy is represented in figure 2-1. The framework is used to make cooperate decisions that are aligned with the company's manufacturing strategy. The framework is based on existing products that are manufactured, new potential products, and the market expectations for the future. When looking at a product, the whole life cycle is analysed which includes after sales service and supply. The choice of product requirement will affect the later selection of process choice and infrastructure. In the following sections each of the steps will be described. (Hill, 2000, ss. 31-32)

Corporate Objectives	Marketing Strategy	Order Winning Criteria	Manufacturing Strategy	
			Process Choice	Infrastructure
<ul style="list-style-type: none"> ▪ Growth ▪ Survival ▪ Profit ▪ Return on investment ▪ Other financial measures 	<ul style="list-style-type: none"> ▪ Product markets and segments ▪ Range ▪ Mix ▪ Volumes ▪ Standardisation vs. customisation ▪ Level of innovation ▪ Leader vs. follower alternatives 	<ul style="list-style-type: none"> ▪ Price ▪ Conformance quality ▪ Delivery speed ▪ Delivery reliability ▪ Volume flexibility ▪ Color range ▪ Product range ▪ Design ▪ Brand image ▪ Technical support ▪ After sales support 	<ul style="list-style-type: none"> ▪ Choice of alternative processes ▪ Tradeoffs embodied in process choice ▪ Role of inventory in process configuration ▪ Make of buy decisions and supply chain management ▪ Capacity size ▪ Capacity timing ▪ Capacity location 	<ul style="list-style-type: none"> ▪ Functional support for operations ▪ Manufacturing planning and control systems ▪ Quality assurance and control ▪ Manufacturing systems engineering ▪ Clerical procedures ▪ Compensation agreements ▪ Work structuring ▪ Organisational structure

Figure 3-1 – Terry Hill's manufacturing model. (Hill, 2000)

3.2.1 Corporate objectives

The choice in the Corporate Objectives will decide what overall objective the corporate strategy want to achieve. It will represent the strategic direction of the business to achieve corporate success. The objective will also decide what parameters that will be suitable for measuring the inputs. Before selecting the strategy, a thorough analysis needs to be performed to make sure that the strategy is aligned with the current state of the economy, markets and existing opportunities. (Hill, 2000, ss. 32-33)

3.2.2 Marketing strategy

After choosing the corporate objectives, a marketing strategy need to be applied and linked with the objectives. The activity often includes three different steps. Establish control units by finding products that have similar market targets and marketing programme. Analyse the product market and determine volumes, define end user characteristics and identify the relative business position of key competitor. The third step is to identify the markets the company want to target and how this should be achieved through short- and long-term action plans. (Hill, 2000, ss. 33-34)

There will also be an agreement on the level of service needed to support the market strategy and the investments and resources that are necessary for obtaining this. The outcome should

include the volumes, mix and range of the product segment to support the strategy and what degree of customizations the products will acquire. The outcome will also declare what position the company will take, market leader or market follower, as well as the when the strategic initiatives will be set into action. (Hill, 2000, ss. 33-34)

3.2.3 How do products qualify and win orders in the marketplace?

When the decision regarding the corporate objectives and marketing strategy has been decided the next step is to identify the product qualifiers and the criteria for winning orders. The focus at this stage is to obtain orders by performing better results than their competitors on the order winning qualifiers. The order qualifiers and winners may be different depending on product and market. (Hill, 2000, ss. 34-37)

The definition of order qualifiers is according to Terry Hill's manufacturing strategy is "those criteria that a company must meet for a customer to even consider it as a possible supplier" and order winners are the criteria that enable the company to win the order. The order qualifiers and winners may be different depending on product and market.

(Hill, 2000, ss. 34-37)

The order qualifier does not need to be included in the manufacturing process but can be criteria as brand name and after-sale service. With this said, the most important order qualifiers are often related to manufacturing. To obtain this, the market function needs to cooperate with the manufacturing function to adapt the demanded qualifiers with the manufacturing process. The importance of an order qualifier may change over time as the market changes and therefore needs to be adapted to the current situation. (Hill, 2000, ss. 34-37)

3.2.4 Process choice

The choice of process is directly related to the order winner and production volume. Therefore, the company has to decide the amount of products that will be manufactured in-house. The company then needs to identify what technologies that can be used to fulfil the technical specifications. When making this decision, aspects such as investments, unit cost and response to its market needs need to be taken into consideration. (Hill, 2000, ss. 35,111-113)

Depending on the choice of process, there will be different trade-offs that need to be addressed. The manufacturing process consists of five generic manufacturing processes which also can be combined into hybrids. The five manufacturing processes are project, jobbing, batch, line and continuous processing. Project is often large scale, nonrecurring products, specifically customized after the customer's requirements. Jobbing refers to low volume production which includes a large range for meeting different requirements from the customers. Batch is used for larger volumes than jobbing where the product design is recurrent. When using the batch process, the production is divided into different tasks which together produce the finished product. In the line process the products are going through a sequence of operations before resulting in the finished product. The process is used for production in large volumes. Continuous processing is for high volume production with a

narrow product range. It is not uncommon for companies to combine two or more processes in their manufacturing. (Hill, 2000, ss. 35, 111-118)

3.2.5 Infrastructure

The manufacturing infrastructure include non-process features in the production as organizational structure, function support and planning and control systems. The implemented supporting functions for communication and internal system should be aligned with the manufacturing strategy. The supporting function exist to enhance the manufacturing performance and to provide strategic support. The infrastructure also includes the capabilities and experience of the personnel involved. To implement the correct infrastructure that suits the strategy it may include high investments for the company and therefore need to be included when evaluating a change of direction. (Hill, 2000, ss. 35-36, 235-237)

3.2.6 Incentives and challenges

In addition to gathering information about the case companies and how their company's manufacturing strategy looks like according to Hill's model for manufacturing strategy, the incentives and challenges that can be identified for the case companies will also be listed. The incentives and challenges will be identified while gathering information to see how the process choice of implementing AM technology in the companies fit into the framework.

3.3 Diffusion theory

There is nothing more difficult to plan, more doubtful of success, nor more dangerous to manage than the creation of a new order of things. . . Whenever his enemies have the ability to attack the innovator they do so with the passion of partisans, while the others defend him sluggishly, so that the innovator and his party alike are vulnerable.

- Niccolò Machiavelli, *The Prince*

The process of getting new products, ideas and technology adopted is called diffusion. According to Rogers even if the new idea has obvious advantages the process is often very difficult. Many innovations require a lengthy period, often of many years, from the time they become available to the time they are widely adopted. The diffusion process is the process of how a new idea, product or technology is adopted widely across a community of individuals. It is often described as a communication process where members of a social system share information about a new idea with each other to reach a mutual understanding of the innovation. Individuals in a social system can be defined as individual persons when talking about diffusion of consumer products. When talking about diffusion of production technology the individuals can be defined as individual companies that have the option of adopting the technology.

In the diffusion process the communication is about something that is new and that distinguishes it from other types of communication. A key factor in the diffusion process is the uncertainty which implies a lack of predictability and information. Information about an

innovation decreases the uncertainty and makes it more clear what the characteristics of the innovation are and what the relationship is between the innovation and the alternatives. Therefore, information and communication processes is important factors in the diffusion process. (Rogers, 1995)

According to Rogers, an innovation has some characteristics that is related to the rate of adoption. The characteristics are relative advantage, compatibility, complexity, trialability and observability. Relative advantage is about how individuals perceive the advantages of the innovation. That can be objective measurements as economic factors but also subjective factors as perceived convenience, social prestige and satisfaction. Compatibility is about how an innovation is perceived as being consistent with the existing values, past experiences and needs of the adopter. Complexity is how an individual perceive the innovation as being easy to understand and to use. The understanding of an innovation in a social system is a factor that increases the rate of adoption. Trialability is the degree to which an innovation can be tested before adoption. If an individual can test the technology on a limited basis and experiment with it, the step to adoption is smaller and the rate of adoption is increased. Observability is how easy it is to see the results and implications of an innovation to others in the social system. If it is easy to see the result it is more likely that the other individuals in the social system will adopt the innovation. (Rogers, 1995)

The characteristics described by Rogers are important factors that needs to be taken into consideration when evaluating incentives and challenges for implementing new technologies. To further analyses the implication in these areas for the introduction of AM technology in the manufacturing industry, the Resistance Model developed by MacVaugh and Schiavone is a suitable tool.

When investigating the diffusion of a manufacturing technology, the market situation is going to be an important aspect. The situation in the market influences how open the companies in the social system are going to be towards new technology. In the case of diffusion of manufacturing methods, the social system is going to consist of the companies that uses the same manufacturing method. In the manufacturing industry the choice of process and technology in the production system is not just a technical question about how to produce products with the right technical specifications. It is also a business question that has to be in line with the corporate objectives and the market strategy. In diffusion of new manufacturing technology these questions are important to understand how the technology fits into a company and how it supports the competitiveness of the company. By using the Model for Manufacturing Strategy developed by Terry Hills the change in strategy can be evaluated when implementing a new process choice.

3.4 Resistance model

The resistance model created by MacVaugh and Schiavone uses a cross disciplinary approach to look at factors that decreases the probability for an innovation to be adopted. The non-adoption of technology is relevant because it investigates reasons for why certain individuals

in a social system will not adopt a technology even though it might be rational and utility maximizing reasons to do so. Technology diffusion is not uniform or inevitable in a social system and it is not something that happens automatically. (Schiavone & MacVaugh, 2010)

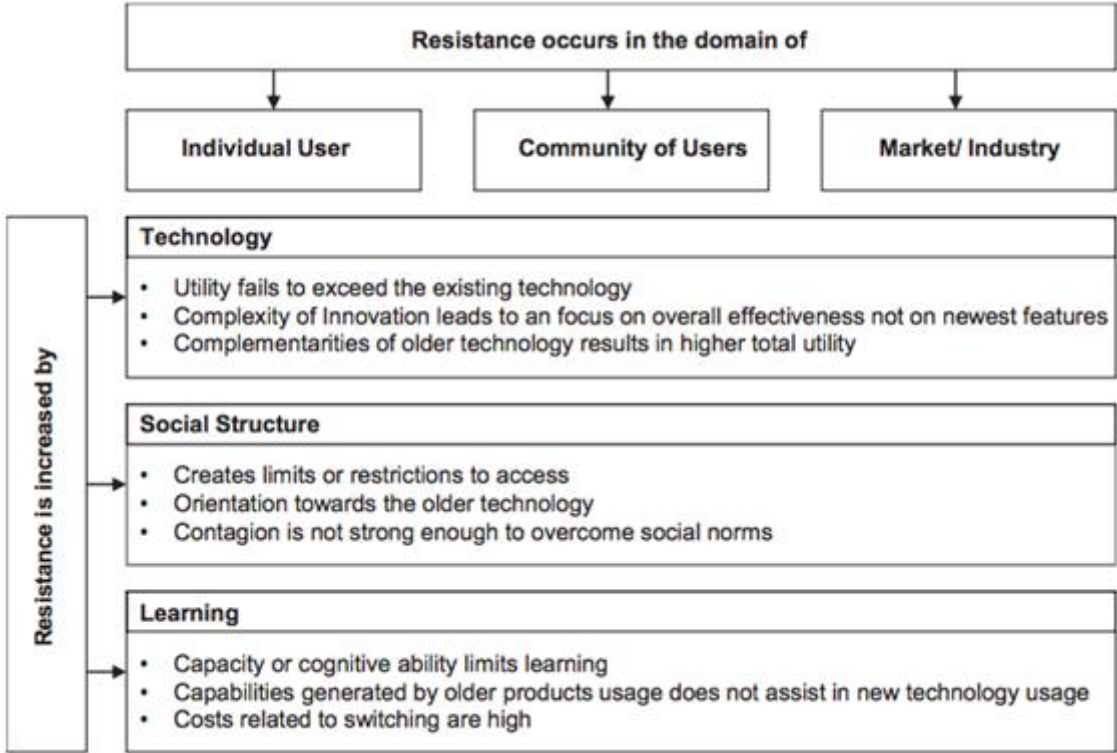


Figure 3-2 - The resistance model by MacVaugh and Schiavone. (Schiavone & MacVaugh, 2010)

To understand the process of technology adoption in an industry it is also useful to understand the reasons behind why some technologies are not adopted and where the resistance to change comes from. From this point of view, the risks and uncertainties are assessed which can give insights that are needed for predicting the adoption of the technology. (Schiavone & MacVaugh, 2010)

According to Schiavone and MacVaugh, new technology adoption can be said to take place within three domains due to the threefold nature of most economic phenomena. The market/industry domain is a (macro) domain of new technology adoption. A second (meso) type of dimension relates to the set of relationships shaping the social system in which the potential adopters are located. Finally, individual (micro) dimension is a third level of analysis likely to support the understanding of this process. (Schiavone & MacVaugh, 2010)

The difference between the domains is perspective that is used to look at the diffusion of an innovation. When a technology is adopted there can be different types of resistance in the different levels:

Market/Industry - In the macro perspective the benefits and drawbacks of the innovation is evaluated of the impact it makes in large economic systems. For example, what the implications would be in switching to a new technology for the manufacturing industry. A

historic example of this is the change from sail boats to ships with steam engines. (Schiavone & MacVaugh, 2010)

Community of users – The meso perspective evaluates how the benefits and drawbacks impact the relationships between different members in a community of users. For example, a group of companies that uses the same technology for the same purpose. (Schiavone & MacVaugh, 2010)

Individual – On the individual level the benefits and costs for switching is evaluated. The individual user can be a single user but also a single company or organization that adopts a technology. (Schiavone & MacVaugh, 2010)

In the model there are three categories of conditions that are affecting the rate of adoption; technological conditions, social conditions and learning conditions.

Technological conditions explain the technical and market features of the technologies that are substituted and substituting. The utility is important for the new technology to create an advantage over the old one. Complementary technologies are an important aspect of the adoption process. If there are a lot of complementary technologies, the probability is higher that the diffusion process will be faster. The presence of industry standards is another aspect which makes it harder for a radical innovation to diffuse. The complexity of an innovation can also reduce the probability of diffusion(Schiavone & MacVaugh, 2010)

Social conditions explain the social context of the individual or company. Within the community of users there can be norms, values and hierarchies that restricts the individual from adopting a new technology. This risk is lower if the individual is the opinion leader, an individual that has a great influence on the rest of the group. Contagion is also a factor which is different depending on the social context. In a community where the contagion is strong the rate of diffusion is going to be faster. (Schiavone & MacVaugh, 2010)

Learning conditions explain the characteristics of the individual that affect the ability to acquire the knowledge and capabilities that is necessary to use a new technology. Aspects of these conditions are capacity or cognitive ability that restricts learning, abilities that were generated by older product use that does not assist in the use of new technology and the cost of switching technology. (Schiavone & MacVaugh, 2010)

3.5 Summary of the theoretical framework

The theory presented above will create a theoretical framework that is going to be used to gather, categorizing and analysing the information from the interviews, the survey and the literature. When constructing the questionnaire for the interviews, the framework is going to guide what information that needs to be gathered in the interviews and in the survey.

The technological audit and the comparison with injection moulding is going to provide a knowledge base that is going to guide what information is relevant to the Hill's framework for manufacturing strategy and how to analyse the information in the resistance model.

Hill's model is going to be used to describe the current situation for the company regarding how their corporate goals and market strategy is in line with their manufacturing strategy. To be able to analyse what the big challenges and incentives there are for implementing AM it is important to understand what implications a change in manufacturing method will have in Hill's model. When changing a manufacturing method, which is a part of the process choice, there is going to be different trade-offs which may support the order winners and order qualifiers in different ways. If those changes are misaligned with the corporate goals and market strategy, it will be difficult for production to argue for an implementation. To be able to draw conclusions from the model it is necessary to get information from all five parts of the model. What the corporate objectives are and how the market strategy is aligned to reach those goals. What the different order winners and order qualifiers are for the market and what implication that has on the production. Those implications will set demands on the production processes and the supporting infrastructure of the factory. These demands will have to be fulfilled if AM technology is going to be accepted. An alternative is to use AM for entering new markets or segments which can imply change in the market strategy and for order winner and qualifiers for those areas.

The resistance model is going to be used to show which resistance factors that are going to be critical for the adoption of the technology and in what domain the resistance is going to be. The resistance model takes a broad approach to the resistance and takes both internal and external aspects into consideration. This broad approach is going to help the analysis to get the bigger picture and what factors outside the company that might increase the resistance.

The resistance model will be used to analyse and evaluate the presented information in the empirics and technological chapter. With the market information disclosed in the technological chapter in combination with the empirics of the interviewed companies the resistance model can adopted to feature the incentives and restrictions for implementing AM in the plastic industry.

4 Empirics

In this fourth chapter the gathered information is summarized and presented. The first part of the chapter the information about the technology in general, the opportunities and constraints is presented. The second part of the chapter the cases are presented with Hill's framework for manufacturing strategy.

4.1 AM technology

This chapter will describe the technology behind AM and what opportunities and restraints that are effecting the rate of adoption in the plastic manufacturing industry. The information is gathered through interviews, a qualitative survey and literature search. The reason for including this chapter is to get an overview of the AM market to understand the investives and challenges the case companies will face during a possible implementation of AM.

4.1.1 AM processes and injection moulding

The different AM technologies needs to be understood to comprehend the challenges with the implementation and what characteristics that can be used as an advantage. There are a range of different techniques for additive manufacturing and some of them are very similar and have been invented due to patent rights. However, there are a few main techniques where there are clear differences and that have gained more popularity than the others. These techniques are explained briefly below together with injection moulding which will be the primary production method of the interview companies aligned with the restrictions of the master thesis. (Gridlogics Technologies, 2014)

4.1.2 AM - Stereolithography, SLA

Stereolithography uses a computer controlled laser to solidify liquid photopolymer. The UV curable liquid photopolymer is in a pool where the laser is tracing out a cross section of the object, solidifying one layer at the time. The object is lowered after each layer and a new layer of photopolymer is applied. An advantage with this method is the good surface finish but the disadvantages are the mechanical properties and that it becomes brittle from exposure of sunlight. (Huang, Liu, Mokasdar, & Hou, 2012)

4.1.3 AM - Fused deposition modelling, FDM

In this process a computer controlled print head is used to build the model. The process uses thermoplastic filament that is extruded through the print head. Two of the materials that can be used are ABS and PLA, which means that the parts made by this process are stronger compared to parts made by the other techniques. On the other hand, it is hard to achieve tight tolerances and a good surface finish with this process. Support material is needed to uphold the structure during the building. (Huang, Liu, Mokasdar, & Hou, 2012)

4.1.4 AM - Selective laser sintering, SLS

Similar with SLA, this process uses a computer controlled laser that traces out cross sections of the model. The difference is that instead of liquid polymer it uses polymer material in powder form that is solidified by sintering. This process makes parts that are more durable and accurate in comparison with SLA but the downside is the grainy finish. Another advantage is that no support material is needed because the powder around the part is holding up the structure. The additional material can be reused. (Huang, Liu, Mokasdar, & Hou, 2012)

4.1.5 AM - Ink-jet printing

This process is similar to 2D inkjet printing and uses UV-curable liquid photopolymer that is jetted in thin layers by a computer controlled print head. After the photopolymer is jetted it is solidified with UV light. The process uses a gel like support material, which is removed after the printing process is finished. This technique has the same pros as SLA but it can produce a better surface finish and it also has the advantage over the other techniques that it can easily use different colours of the material in the same model. (Huang, Liu, Mokasdar, & Hou, 2012)

4.1.6 AM - Three dimensional printing, 3DP

In 3DP the material that is used is similar to the materials used in SLS. The powdered material is deposited on a substrate that is selectively joined using a binder that is sprayed through a computer controlled nozzle. The material is stabilized by misting with water droplets on the material surface. The layer can also be further strengthened by applying heat before applying a new layer of material. It is a fast process with low material waste but the surface finish is poor. (Huang, Liu, Mokasdar, & Hou, 2012) (Falkenberg, 2016)

4.1.7 Injection moulding

Due to the delimitations of the master thesis, all of the interviewed companies will use injection moulding as their primary production method. A key question that has to be investigated in the interviews is to identify for what applications and in what areas AM can be used and whether the technology will be used as a complementary method or overtake current production activities. This must be investigated because that will lead understanding of the incentives and challenges that the companies face when adopting AM technology. Therefore, the technology chapter will include a description of injection moulding to understand the differences to AM.

Injection moulding is today one of the most used methods for producing plastic articles from raw material. The method has been used for thermoplastics since the 1920s but the method was not applied on a large scale until the 1950s. The injection moulding used today in the plastic industry are fully automated machines with the potential to produce high volume product series. (Morris, 2001)

The process works by injecting polymeric material into a heated barrel. The state of the polymeric material at this stage is either in powder or in granulate form. The material is melted in the barrel and injected into a mould with the help of a plunger arrangement, using a screw pushing the material forward as presented in figure 4-1. To contain the polymeric material within the mould, it is closed by applying pressure. A clamping pressure of 150N to 4000kN is used to prevent leakage. The polymeric material is solidified within the mould by applying temperature below the thermoplastic melting point. When the material has been contained within the mould for the predetermined cooling time, the mould is opened and a solid object be ejected. (Morris, 2001)

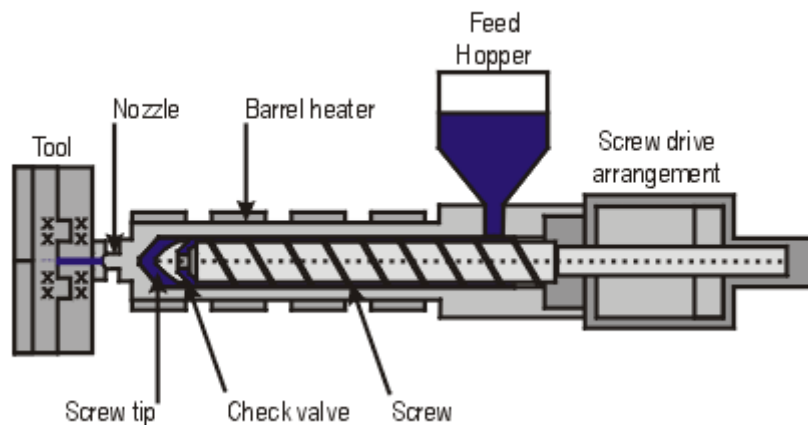


Figure 4-1: Injection moulding. (Morris, 2001)

Injection moulding is a very common manufacturing method in the plastic industry and the range of materials is very broad. All types of thermoplastics and silicones are used and often injection moulding companies work with a high number of different materials. (Samuelsson, 2016)

One advantage with injection moulding is that the cycle time is low which varies depending on the complexity and size of the object being produced. By using multi-cavity injection moulds, high volumes can be produced by repeating the process. Injection moulding also gives the manufacturer a large variety of material to choose from and can produce products with high precision (Morris, 2001). While the cycle time is low the introduction and modification of products can be time consuming. When a modification is being applied, a new injection moulding tool has to be manufactured. The production of new injection mould also demands an investment from the company. Injection moulding is often used for large scale production which means when the economy of scale is considered, the cost per unit is reduced. The cost of investing time and money on a new mould is one of the disadvantages with the method.

Another aspect to consider is the design process for injection moulding. The design is often made in a software supporting the creation of 3D-model. What needs to be considered when making the models is the ability to later manufacture the product with injection moulding which means some restrictions in the design process. (Falkenberg, 2016)

4.2 Additive manufacturing – Technology audit

To understand the incentives and challenges the companies might have to adopt AM technology, it is necessary to get a picture of what the technological advantages are and how they may be commercialized by a plastic manufacturing company. This section will describe the technological advantages and limitations and the future market opportunities and challenges. Research from academic papers and interviews with experienced people within

this area will be included to receive the perspective of the whole plastic industry of the potential strengths, weaknesses, opportunities and threats for the implementation of additive manufacturing.

4.2.1 Advantages

To evaluate the implementation of the technology in the plastic industry it is important to know the advantages of the current technology state and for what applications AM is used for. One of the most used applications that have been widely adapted in the plastic manufacturing industry is rapid prototyping. The benefits with using rapid prototyping are that the design and functionality of the products can be evaluated at an early stage in the development process. (Diegl, 2016) This also makes it possible to present a 3D-model for internal departments and costumers to show the feature of the finished products (Falkenberg, 2016). Rapid prototyping can also be used for functional testing if the mechanical properties are sufficient.

In comparison with some of the conventional production processes like injection moulding, AM does not require any cost for tooling. The conventional methods are cost efficient when it comes to mass production of standardized products but AM has an advantage in low volume productions runs with high value products. Also the cost of geometric complexity is lower with AM in comparison with for example injection moulding where the geometric complexity is related to the cost of producing the mould. With AM the need for assemblage is lower because of the possibility to consolidate multiple parts into one part that can be produced in one step. (Gao, o.a., 2015)

Additive manufacturing makes it possible to produce customized products for low volume production. The advantages with the technology makes it possible to overcome previous restriction for other manufacturing methods as complex designs and lead-time. Instead of having to invest and wait for tooling, unique products can be produced by using AM direct from the design suggestions. This application is used in the medical industry where one customer often differs from another. One example of this is hearing aids produced with SLA according to the customer's design preferences. (Diegl, 2016)

Another area where AM is used is to improve properties for existing products. One example of this is to reduce weigh by using a honeycomb structure. This is a valuable attribute in aircraft industry where a reduction of one kilo reduces cost by about 30 000 dollars a year. With a potential material reduction of 30-60 percent with AM technology, large savings can be done in this area. (Diegl, 2016)

4.2.2 Limitations

Recognizing the limitations for AM technology is also an important factor to consider. One problem today is the material shortage. The material properties must meet the standards of the considered products and the existing materials today are restricted in this area (Diegl, 2016). This also include the supporting material that needs to be removed after production.

According to Evald Ottosson from Protech, a large amount of the time spent experimenting with new material suggestions is spent on finding supporting material that meets the expected properties (Ottosson, *Plastteknik Nordic: Seminar on 3D-printing*, 2016). The largest material variation today is within FDM which indicates that it is the easiest method to develop new material for (Sohlberg, 2016).

A large share of the current AM machines is not compatible with all of the existing AM material. The system is often developed to only run specific material from one supplier and there needs to be a software change before making it compatible with other material. This has become an instrument for machine and material suppliers to prevent users from using other materials than their own due to the software change often demands a large investment from the user (Diegl, 2016). Often service agreements for the machines does not apply when using other material sources (Sohlberg, 2016).

It is a consensus that material development is a high priority in the AM industry. The large companies are putting a lot of effort in developing new materials. (Ottosson, *Survey: Protech*, 2016) (Shams, 2016). According to Shams from PLM group, a reseller for 3D-systems, 3D-systems call themselves a material company rather than a machine company to communicate the focus on material development. The development of the machines is going to be more evolutionary with incremental improvements of build area and productivity. However, if there comes a revolutionary new AM process it is going to change the way we look at the AM process completely. (Shams, 2016)

There seems to be no consensus about if the business model of the machine and material suppliers are going to look like. The large machine suppliers do not have open source for materials for their machines and although they develop their own material they also create partnerships with specialized material developers to get more capabilities in this field. The uncertainty for whether open source is going to be best practice in the future is very high. (Kristiansson, 2016)

The cost of the material is also a factor that restricts plastic manufacturers from implementing AM for larger volumes. The low end machines have a material cost around 200-300 kronor/kilo but are not up to standard for industry level products. The high end machines can have a material cost around 2000-3000 kronor/kilo. This makes it hard to compete with other manufacturing methods as injection moulding and as discussed before it does not always include applicable materials to achieve production standard. (Diegl, 2016) (Ottosson, *Plastteknik Nordic: Seminar on 3D-printing*, 2016)

Another disadvantage with AM manufacturing is the post production process. All of the AM technologies today include some form of post processing and should not be neglected. This can increase the cycle time in the manufacturing process and prevent manufacturing of large production series if not automated with the help of CNC machines and robots. (Diegl, 2016)

One factor that has come up in interviews and in the survey is the repeatability and reliability of the process. The reason for mentioning its importance is because it has to be certain that the result is the same every time. In AM technology the machine and the material is very closely linked together, which is a reason for why the machine companies have strong ties to their customers when it comes to supplying material for them. (Ottosson, Survey: Protech, 2016)

Other restrictions mentioned in the survey are the print size, the speed and the surface resolution (Ottosson, Survey: Protech, 2016) (Shams, 2016). According to Ottosson an aspect that can affect the possibility of integrating AM technology in manufacturing systems is the reparability of the machines. He says that the reparability of AM machines from all brands in the market must improve. (Ottosson, Survey: Protech, 2016)

4.2.3 Future opportunities

Due to technology development of both AM techniques and material there is potential to use AM for new applications and to ramp up current application areas. One area where AM can be the reason to large alterations is within the supply chain. By printing products on demand at the closest location, the need of large warehouses for stock holding and product transportation can be reduced (Diegl, 2016). Instead a possible scenario would include an electronic collection with files of the products ready for printing. Tetra Pak have investigated the possibilities for producing spare parts with AM. There are two reasons for Tetra Pak to look into this; primarily it is to reduce the stock levels of rare spare parts that could be made on demand and secondarily to reduce lead time for the customers to receive their spare parts. When it comes to reducing the lead time to the customers there is also a possibility to produce temporary spare parts in plastic that can be produced locally and then wait for the regular spare part to arrive. The reason why this is important for Tetra Pak is because down time in production is very costly for their customers in the food industry and services to reduce down time are high value services for Tetra Pak. This application for AM is already used by Tetra Pak in Japan who delivers temporary conveyer spare parts to their customers to prevent downtime. (Nilsson, 2016)

As discussed in the advantages chapter, with the use of AM, existing products can be altered to receive characteristics that are important aspects for some products. According to Lars Sickert, who works with front end innovation at Tetra Pak, this is an area that has not been fully exploited yet. Sickert believes that there is large potential in manufacturing certain parts with AM technology that have advantages over the parts made by conventional manufacturing. The advantages he means are to reduce the weight, increase heat resistance due to hollow structures, consolidate details and make geometries that cannot be manufactured in a conventional way. Sickert says that there is a possibility of producing 15% of their parts by 3D-printing. Another area that Lars Sickers believes that there is great potential in is the development of AM in multiple materials, so that a part with steel, rubber and plastic could be made in the same process. Rickard Nilsson at Tetra Pak says that it is difficult for them to review which of their products in their portfolio could be produced with AM partly because they do not have the knowledge of how to optimize design with AM and

partly because it is a large amount of existing products in their portfolio. (Nilsson, 2016) (Sickert, 2016)

Another application area that are used today and can increase in the future is producing moulds for injection moulding. The lead-time for standard tooling manufacturing today are often very long and demands a larger investment. With AM the moulds can be produced in less time to a reduced cost and used for smaller series in manufacturing. (Falkenberg, 2016) (Sickert, 2016)

Another possible scenario is the ramp up of production quantity with additive manufacturing. The most recent number for comparing the cost between AM and injection moulding are 1000 units for a cell phone size object. The opinions regarding the future breakeven cost between these technologies are divided but according to Olaf Diegel, professor at Lund's Technical University, the number can increase to 5-10 000 units depending on the size and complexity of the object. Diegel expresses that with volumes larger than 10 000, other manufacturing methods should be looked into. With new actors entering the AM market, the competition can lead to reduced prices for both material and machines. This will also be a factor that will affect the breakeven cost between AM and other manufacturing methods. The most suitable AM method for manufacturing today is SLS. (Diegl, 2016)

In the survey there seemed to be consensus about that metal AM have very large potential. In the manufacturing industry, large economical savings and rationalizations that can be made with the use of AM technology. (Shams, 2016) (Nilsson, 2016) (Kristiansson, 2016)

4.2.4 Future challenges

There are both internal and external factors that may increase the difficulties in implementing AM technology. One factor is the capabilities regarding the AM technology with plastics manufacturers today. Many companies are focusing on other manufacturing methods as injection moulding and have structured the company after that process. This means that the experience and knowledge often are largely restricted to the standard manufacturing methods. With the introduction of AM many companies believe that new capabilities need to be introduced in the company either by education of current personnel or by employing new personnel. To be able to use 3D-printing technology successful, companies have to know how to design products in a way that they get the advantages that AM have which require new design capabilities. One way to increase the knowledge of AM is by implementing AM education at schools in Sweden. This is an area where Sweden is behind other countries as Germany and USA with multiple existing educational programs in this area. (Falkenberg, 2016) (Ottosson, Plastteknik Nordic: Seminar on 3D-printing, 2016)

Even though there will be improvements for AM technology it is important to differ the layer on layer technique used by AM and Injection moulding technology. According to Mikael Solberg from GT prototypes, AM technology will never be produce the same level of properties as the ones you receive from injection moulding. (Sohlberg, 2016)

Another threat to the implementation of AM in the plastic industry is a possible stagnation of technology development for AM. To reach new application areas the technique needs to be developed to be able to supply additional material selections, improve speed and improve mechanical properties. The industry expect improvement in all of these areas but the time interval for development is hard to identify. Material development is one of the biggest challenges and also something that the major companies put a lot of their R&D resources into. (Ottoosson, Plastteknik Nordic: Seminar on 3D-printing, 2016)

In the possibilities of using AM to produce spare parts on demand instead of keeping them in stock there is a few constraints that is making it difficult to adopt the technology. According to Rickard Nilsson at Tetra Pak it is a lot of work in testing the parts produced with AM to make sure that they fulfil the requirements needed to be able to be used in a machine. When it comes to replacing metal parts with AM produced plastic parts there is the same problem that they have to be tested to be able to commercialize. Another aspect that is relevant for Tetra Pak is that the surface finish that is required for a lot of the parts cannot be achieved with AM. (Nilsson, 2016)

4.3 Hill's framework for manufacturing companies

This section consists of the results from the research of the six different case companies. The selection process of the companies has been according to the criteria's formulated in finding the interviewees in the theory chapter. The delimitation for the selection process of the case companies will be used to accomplish a comparable analysis based on the empirical findings. The companies are evaluated based on the framework for manufacturing strategy developed by Terry Hill and additional information about incentive and challenges for implementing AM are included.

4.3.1 Case I: Atos Medical

Atos Medical is a plastic manufacturing company located in Hörby. Atos specializes in products for laryngectomy patients. Patients with laryngectomy cannot breathe through their mouth and nose but are instead forced to breathe through a hole in the person's throat called a stoma. Atos Medicals products are developed to make the customers life as easier by smart solutions. Atos medical introduced their first product for this application 25 years and have since then provided 70.000 customers with laryngectomy products. Atos medical are today the leading company in their field and have 400 employees with daughter companies in many countries. (Falkenberg, 2016) (Atos Medical)

Examples of products manufactured for Atos Medical's customers are plastic bandages with adhesive that are attached to the customer's throat, a check valve with a HME (heat and moisture Exchanger) that helps to dehumidify the air and reduce cough and mucus production. They also manufacture voice prophesises. For simplifying their customers' daily life further, Atos medical also manufacture a products developed to enable hands-free speaking. The products are made in silicon and polymer material and their primary production method is injection moulding. (Falkenberg, 2016)

4.3.1.1 Corporate objectives

Atos medical are having a growth strategy by approaching new market and continuous product development. Additive manufacturing is not part of the objective to increase market shares but instead tying existing customers to the company by supplying customized products. (Falkenberg, 2016)

4.3.1.2 Marketing strategy

Atos medical is currently the leading company in the laryngectomy industry and intend to keep this position by investing in innovations and improving existing products. The only area where they have any real competition is within bandage manufacturing. Atos Medical are manufacturing standardized products and can produce high volumes in their production. They produce around 5 million bandages every year in different forms and sizes. Their specified products, as the bandage for attaching the voice prosthetics, have a production volume of 500 000 units/year and the prosthetics themselves have a production volume of 80 000 units/year. (Falkenberg, 2016)

To get knowledge of the market and what are demanded of laryngectomy patients, Atos medical have completed an extensive market analysis with help of an external source. The market analysis is used when deciding what new applications that will be developed and invested in and support the selection of product range and mix. The company's experience in taking patent on products is one important aspect in their success. (Falkenberg, 2016)

4.3.1.3 How do products qualify and win orders in the market place?

Atos medical has good margins on their products which also are subsidized. The order winners for the company are the quality and functionality of their products. This has led to a top position in the industry and are kept by having a high introduction rate of product innovations. The same criteria's can be seen as order qualifiers where also cost can be included. Another way to keep the competitors away is by having patent on products, which is widely used by Atos Medical and ensure market access. By implementing additive manufacturing, the functionality and fitting of products may increase due to customization which is aligned with the current order winners. (Falkenberg, 2016)

4.3.1.4 Process choice

Atos medical is currently using injection moulding for their production. They have personnel working in two shifts, five days a week running the injection moulding machines and the post production handling which consist of controlling the products and package them. The post production is relatively time consuming because of the high quality requirements. If changing to AM, the manufacturing and post production processes will probably include even more manual handling if the processes are not automated. Due to the standardized production in large volumes divided in batches, injection moulding is a suitable choice. The injection moulding has been brought in-house to keep control over the production and costs. (Falkenberg, 2016)

One disadvantage with the injection moulding is the development of tools which can be time consuming. The company introduce 3-4 new product every year to meet the customer demand. This means that large investment in injection moulding tools are necessary and the delivery can take 8-13 weeks depending on the size and complexity. The products need to be validated and undergo a number of test to ensure customer health and correct functionality. The project time of introducing a new product can take 1-2 years. (Falkenberg, 2016)

Rickard Falkenberg does not see AM as a production method that will take over but instead a complementary method for specific products. If they use AM as a complementary manufacturing method the personnel can divide their time between the different machines because of the high automatization in the injection moulding process. (Falkenberg, 2016)

4.3.1.5 Infrastructure

The infrastructure at Atos Medical is structured to support their manufacturing method. The capabilities and experience of the personnel are focused on injection moulding and the processes from development to manufacturing are integrated to enhance the production. With only a small portion of manufactured products made from additive manufacturing, there will not be any large alteration in this area. What changes that will have to be made and how that affect the production system as a whole is hard to say and nothing that Falkenberg is worried about at this stage. To receive capabilities about AM, one alternative is to employ personnel with these qualifications. (Falkenberg, 2016)

Atos daughter companies that sell their products abroad have the same ERP-system which makes the information flows faster to the production. This makes the process of ordering customized products faster and will be an advantage if implementing AM technology. (Falkenberg, 2016)

4.3.1.6 Incentives to adopt additive manufacturing

When it comes to the utility of AM technology in comparison with injection moulding, it is the possibility to mass customization that is the primary technological advantage in their opinion. What they are interested in is to customize their products to their patients which increases the value of the product and strengthens the ties between the customer and Atos. (Falkenberg, 2016)

They do not think that AM will be able to compete with injection moulding in their case because of the low cost for their typical volumes they have with injection moulding. In their opinion AM will have to contribute with something unique like customization that increases the value of their products. When it comes to drawbacks with AM it is the cycle time and the cost that is the two most important ones but the informant also says: "But if you can find sufficiently large advantages with the application, maybe it will have to cost". (Falkenberg, 2016)

When it comes to the medicine industry, the knowledge about the advantages with customization for the customer is high. The medicine industry is adopting AM technology for many different purposes like making prosthetics. (Falkenberg, 2016)

The current use of additive manufacturing has been for prototyping in an early stage. Falkenberg believe that there would be much value to be able to present a physical product for customers and the marketing department early in product introduction process instead of just a drawing. This would be an application suitable for additive manufacturing. They have plans on investing in a desktop printer for the lab to learn more about the possibilities with the technology. (Falkenberg, 2016)

4.3.1.7 Challenges to adopt additive manufacturing

Due to the high production volumes of the existing products additive manufacturing will have difficulties in competing with injection moulding according to Falkenberg. The injection moulding technique has been around for a long time and the company already have the experience and capabilities to use the method in an efficient way. Falkenberg believes that one of the drawback with switching technology would be increased cycle-time. He is also worried about post processes connected with AM which would have to be automated if used for higher volumes. (Falkenberg, 2016)

Another resistance factor is the lack of materials for 3D-printing. One thing that is crucial according to Falkenberg is the material properties. The material needs to be biocompatible, soft and have a good surface finish because of the direct contact with human skin. This is something that needs to be guaranteed by the material supplier to enable the implementing additive manufacturing. Falkenberg expresses a concern for the limited material choice for additive manufacturing because of the limitation already existing for the material selection for injection moulding. (Falkenberg, 2016)

According to Falkenberg one factor of resistance is the design process. He says: "We think in terms of injection moulding when we design a product. We do that already in the prototype stage. If we would have used 3D-printing, we would have gotten more freedom I think". That is a resistance factor that limits the learning of how to design products in a way that takes advantage of the possibilities that AM technology has. Atos clearly have gathered a lot of capabilities and knowledge about injection moulding which makes the oriented towards that technology. Those capabilities will not be useful when integrating AM technology and the operations and development organization will have to reorganize how they work. That is one of the reasons why they do not think that AM will replace injection moulding but it will complement it for some of their products. (Falkenberg, 2016)

4.3.2 Case II: Nolato MediTech AB

Nolato MediTech AB is located in Hörby and manufacture plastic products mostly for customers in the medical sector. The company is a part of the corporate group Nolato, which have daughter companies that focuses on different markets. Their production method is

injection moulding in different plastic and silicone materials. Nolato MediTech AB also have a production unit in Lomma. For additional service, Nolato MediTech AB offer further processing and product assembly to their customers. (Nolato Meditech) (Johansson & Bengtsson, 2016)

4.3.2.1 Corporate objective

The corporate strategy of Nolato MediTech is to increase their market share in the plastic, silicon market for medical applications. AM does not necessary fit in the corporate strategy at the moment as the implementation of the technology only is at the discussion stage. (Johansson & Bengtsson, 2016)

4.3.2.2 Marketing strategy

Nolato MediTech have historically been involved in many different segments, in the plastic and silicone industry, baby care, cosmetics and life stock. Even though there still exist products from these segment the main focus is today the medical industry which include manufacturing and refining products in different stages. The largest competitors exist in the plastic segment while the company is the primary actor in the silicon segment for medical products. (Johansson & Bengtsson, 2016)

The aim is to keep their high standard of product quality and customer service to retain their international customers and keep them from sourcing closer to their headquarters. The company are not developing any products on their own but solely on customers' request. Based on the customers' preferences a request can be anything from exclusively developing and performing test on the product to performing the manufacturing. The company have currently not received any request from their customers that would include additive manufacturing. (Johansson & Bengtsson, 2016)

4.3.2.3 How do products qualify and win orders in the marketplace?

According to Nolato MediTech, the company wins their orders by being cost efficient, having high quality and supplying a high level of customer service. By offering low prices and high quality the company can prevent their international customers from finding better alternatives located nearby. Additive manufacturing would be a part of the customer service by showing design suggestions at an early stage. With AM technology, cost efficiency would not be able to compete as an order winner for medium to large volumes. (Johansson & Bengtsson, 2016)

4.3.2.4 Process choice

Nolato MediTech is exclusively using injection moulding or version of the technique as their manufacturing method. Additive manufacturing has no place in the manufacturing process according to Nolato MediTech. The simple geometric figures of the products and the large production volumes makes additive manufacturing redundant. (Johansson & Bengtsson, 2016)

4.3.2.5 Infrastructure

Nolato Medical are focusing on improving injection moulding and are not looking for other techniques to replace the manufacturing method. This means that the current supporting systems that are meant to support injection moulding will continue to be sufficient in the future. The small portion of use for additive manufacturing will not change the infrastructure but will instead be used early in the introduction stage for design confirmation. The company are using IFS as their ERP system. IFS are used for order entry, production control, product delivery and purchasing. (Johansson & Bengtsson, 2016)

4.3.2.6 Incentives to adopt additive manufacturing

Making injection moulding tools are currently the application that seems most useful to Nolato. That could help them to shorten the lead time for receiving the moulds and start the production earlier. This application is then meant for their silicon product where a plastic mould could be produced with AM methods. Another area where AM could be used according to the informants is for prototyping and showcasing product design for customers. (Johansson & Bengtsson, 2016)

4.3.2.7 Challenges to adopt additive manufacturing

According to the informants the important things they want from their production process is quality and cost efficiency. They have high demands from their customers and competing on their efficiency and quality. The informant says that quality is very important in the medical industry and measures like surface resolution and biocompatibility have to be met by AM if implemented. (Johansson & Bengtsson, 2016)

The informants say that the available AM machines today are not made for the purpose that they would like to use it for. They do not produce parts with the right resolution and not fast enough. They said: "There are products today that can be produced well with AM but then the cycle times are too long and will not be able to compete. The ones that goes faster does not fit our customers because the uneven surfaces and so on." AM technology does not have the right performance when it comes to speed and quality. (Johansson & Bengtsson, 2016)

Nolato is focusing on operational excellence and being a competitive sub-contractor and expert at producing products in their markets. They are focusing on being good at what they do and therefore they have a very strong orientation towards their current technology which mainly is injection moulding. They came in contact with AM during the 90s. Then it was about making prototypes and that is still the application they think they might use it for. The informant is relatively negative towards 3D-printing and think that it is a lot of hype around it but it will not be able to compete with injection moulding for their current applications. (Johansson & Bengtsson, 2016)

"I feel like this with the hype, I think it has come so many new cheap models that is not really aimed at our business. More towards consumers. I know model builders that are lyrical over

their 3D-printer, but it is not what we need. On exhibitions everything looks basically the same and has the same quality and speed." (Johansson & Bengtsson, 2016)

Being a subcontractor to other companies makes them dependent on their customers and how they want their products to be produced. They give their customers input in the designing stage mostly about the manufacturability of the products. (Johansson & Bengtsson, 2016)

When asked how they come in contact with new manufacturing technologies the informant says that there are journals, fairs and exhibition but foremost they are learning with and from the customers and get a lot of new ideas from them. (Johansson & Bengtsson, 2016)

4.3.3 Case III: Kanor Plastic

Kanor Plastic is a small family owned company that was founded in Malmö 1957 by Kaj Nordström. Today the company is owned and operated by his son Lars Nordström. The company is producing both their own products and products for sub-contracting manufacturing. The method that is used is exclusively injection moulding with thermoplastics. (Nordström, 2016)

4.3.3.1 Corporate objective

Kanor Plastic is a relatively small company who adapt to the market demand. By having a couple of loyal customers they can stay competitive. The company are not working with the larger volumes and are therefore not competing with the big actors in the plastic manufacturing industry. They are focusing on survival and being a competitive partner to their customers. (Nordström, 2016)

4.3.3.2 Marketing strategy

The company are currently having an equal amount of own products and products developed after customers' technical specifications. One area where Kanor Plastic develop their own products are within the medical industry. Kanor Plastics says that they do not have any specific marketing strategy but adapt to the situation by helping customer to find solutions. By conducting their assignment in a professional way and deliver good results to their customer, they are able to receive new customer based on their reputation. If customers continuously request products that demand the involvement of AM, the company are prepared to invest in an AM machines. But Lars Nordström also express that if the demand for AM manufactured products are low there is an alternative to buy these products from other companies and make it possible to focus on the core business. (Nordström, 2016)

4.3.3.3 How do products qualify and win orders in the marketplace?

Kanor Plastic are winning their orders by supplying good quality products and innovative solutions for their customer. By focusing on nearby customers and a close customer relationship, they are able to keep customers for new projects. Because of the lack of customer request on AM manufactured products there is currently no need for AM to qualify or win orders. (Nordström, 2016)

4.3.3.4 Process choice

Kanor Plastic is using injection moulding as their only production method. Part of the design process is outsourced with a constant involvement from Kanor Plastic regarding specific details. The products that they own themselves are made to stock and the products owned by their customers are made to order. That gives them a freedom to produce their own products when they have free capacity and when they have a lot of orders they can focus on those orders, keeping the delivery time down and increasing the service level. (Nordström, 2016)

AM technology is solely used for prototyping but are then sourced from suppliers. Nordström cannot see any specific product in their current product range that needs any improvement by implementing additive manufacturing and therefore there is no need to invest in any new production choice at the moment. (Nordström, 2016)

4.3.3.5 Infrastructure

Due to the size of the company there is no need for any complex supporting system. Activities that the company perform in-house are logistics, production and sales. If implementing AM in the future by buying the machines, the personnel would need to be educated in this area. According to Lars the implementation of AM is not something that currently is relevant and therefore the existing infrastructure is sufficient for their processes. (Nordström, 2016)

4.3.3.6 Incentives to adopt additive manufacturing

The informant does not think that there is any incentive for them to use AM technology in house. They use it for prototyping and that is the only relevant application for them. Making spare parts with AM to reduce transportation costs and lead time is an interesting application but not a business that they will go into. (Nordström, 2016)

4.3.3.7 Challenges to adopt additive manufacturing

In most cases Kanor produces volumes that are too high for 3D-printing but there are some cases where the volumes are below 10 000. In these cases, it does not make sense to produce it with 3D-printing because according to Nordström it is too inconvenient to change and too uncertain if it will have an advantage. He brings up Tetra Pak as an example where they have produced short series of details that was in a trial period. There it could be an advantage that the lead time would be shorter and that they would not need to invest in injection tooling. If the detail would come into regular production it would probably be injection moulded. (Nordström, 2016)

Orientation towards the old technology is strong. They are trying to survive and keep their current customer by being competitive in injection moulding. Nordström express that contagion effects may be a factor when their current customers ask them to produce something that cannot be injection moulded. (Nordström, 2016)

When Nordström is asked if they work a lot with local customers he says: "Yes we do. Swedish local rooted companies that we work together with development. A lot in this

industry has moved to Asia due to lower costs. Shorter series has not disappeared and medium volumes are coming back due to the shorter lead times" (Nordström, 2016)

The investment in time and money for a small company to learn how to use AM is very high. They do not invest so much in getting new input on the developments in the industry in general so the knowledge they have on how they might use AM is low. In the design process they use 3D-printing to produce prototypes but they outsource it to an external partner. To expand their business with AM for other types of products is not in their interest because their focus is more on survival and keep their current customers by being a reliable injection moulding partner. He is not worried about the competition from AM. (Nordström, 2016)

Another resistance factor is that he does not use CAD to make sketches. If he would invest in a 3D-printer he would also need to invest in a CAD program, which is a large investment for a small company as Kanor. (Nordström, 2016)

4.3.4 Case IV: Prototal PDS

Prototal PDS is a company who was created in 1996 in Vinninga. Today they are a sub contract manufacturer with the potential to supply their customers with prototypes and products manufactured with AM, injection moulding and vacuum casting. The company is included in the Prototal Industries concern since 2012 who has operations in Jönköping, Trollhättan, Stockholm, Vinninga and in Norway. (Anteryd & Stadling, 2016)

4.3.4.1 Corporate objective

They have a growth strategy that is focused on some areas and in other areas the strategy is to maintain the market share. Vacuum casting is a business area which is relatively constant while in injection moulding and tool making they have grown the last years. The strategy is to be a broad subcontractor that can provide many services in a competitive way. Being a part of Prototal they also get synergies effects by having access to each other's capabilities. (Anteryd & Stadling, 2016)

4.3.4.2 Marketing strategy

Prototal PDS marketing strategy is to adapt to customer request regarding developing design, prototypes and manufacturing. The customers are often development agencies. At the moment they have one product that is their own creation. A normal situation is that the customer presents a design solution that they want Prototal PDS to produce prototypes for and possibly manufacture. The company also offers to assist in the development process for smaller projects. The most usual orders that includes AM are for prototypes. (Anteryd & Stadling, 2016)

By supplying many different markets and customers, the company can reduce their sensitivity to market fluctuations. They have no customers today that are responsible for more than 10 % of their sales. The company manufacture products in both small and large batches. They

currently only have one product that is produced in numbers over 100 000 units/year. The most common volumes are 8-10 000 units/year. (Anteryd & Stadling, 2016)

4.3.4.3 How do products qualify and win orders in the marketplace?

Prototal PDS are winning orders on quality and customer relationship. By being a reliable supplier to their customer they are able to secure future cooperation with current customers. The company believes that it is important to initiate an early dialogue with their customers regarding lead-time and delivery date. If the customer requests a lower price it can often be solved by prolong the delivery time. The company often does not want to be involved in the development process to prevent to compete with their customers. (Anteryd & Stadling, 2016)

4.3.4.4 Process choice

The processes being used today for manufacturing by Prototal PDS are injection moulding, SLS, projet and vacuum casting. The larger volumes are produced with injection moulding and additive manufacturing can be used for prototyping and smaller series that can go up to 100-1000 units. AM is also used when time to market is an important factor. Then AM products can be used during the start-up time for injection moulding and can later be replaced if preferred. The possibility to include SLS is decided by the size and complexity of the products and the costs are often too high for manufacturing larger objects with AM. By having alternative process choices, the company can offer their customers more freedom when it comes to design and material properties. Prototal PDS also produce their own tooling for injection moulding. (Anteryd & Stadling, 2016)

4.3.4.5 Infrastructure

Prototal PDS have the in-house capabilities to support all of their manufacturing process. By having personnel that are responsible for each method they can secure that people with the proper experience at the right location. By already having the existing infrastructure and capabilities to support additive manufacturing, a potential expansion to increase capacity would narrow down to the investment in new machines. (Anteryd & Stadling, 2016)

4.3.4.6 Incentives to adopt additive manufacturing

With the high level of integration of AM technology, the informants are already familiar with some of the advantages with using AM. By conducting experiments on material properties for AM products, the company have an idea of what applications the technique that useful for. With the infrastructure and capabilities already existing within the company it can be used as an incentive for further development to eventually create a better service to their customers. (Anteryd & Stadling, 2016)

The customer knowledge about AM differs depending on what customer it is and are often higher if they have a development department in-house. According to the informants, the use for AM can increase when the knowledge spreads and more customers start to ask for AM

manufactured products. An important aspect here is that the industry needs to learn to design with the AM technology in mind and not be restricted by designing for conventional production methods. The informants believe that the industry knowledge will increase with the implemented academic learning of AM at universities today. They have seen that customers sometimes are resistant to swift from AM to injection moulding because of the freedom of geometry for the products that AM enable. (Anteryd & Stadling, 2016)

Another incentive is the possibility to use AM for faster market access for their customers by when waiting for larger quantities produced with injection moulding. The informants also see potential to use SLS as a replacement for processed metals and is something that they are already using for some applications in their own production. (Anteryd & Stadling, 2016)

4.3.4.7 Challenges to adopt additive manufacturing

The informants also see some challenges in the future for the AM technique. They are a regular user of the SLS method and are content with the robust material properties. What the technique lack is the ability to produce good surface finish according to the informants. The interviewees express that the dream scenario would be a printer with the possibility to print with the mechanical properties of SLS and the surface finish of SLA technology with quick cycle time. This would decrease the need of investing on different machines to be able to supply their customers with a several options. (Anteryd & Stadling, 2016)

Another aspect that is missing is the possibility to print in soft material and the informants believe that material development would benefit the company by having more material options to propose to their customers. The company also says that activities involved in handling the epoxy material for SLA today are tough and the SLS method is preferred in that aspect. Protocal PDS is familiar with the FDM method but believe that it is too slow for applicable use for them. (Anteryd & Stadling, 2016)

4.3.5 Case V: Frohe AB

Frohe AB was purchased by the current owner in 1991 and is a plastic manufacturer who supplies injected moulded products to the medical, automotive, agriculture and appliance industries. Frohe AB has one production site in Tyresö, Sweden and one in Wroclaw, Poland, who also does assembly of products. In total there are 120 employees working at Frohe AB, 70 in Sweden and 50 in Poland. (Samuelsson, 2016)

4.3.5.1 Corporate objective

Frohe AB was earlier a supplier for the telecom business but changed direction after the telecom boom in the early 2000. Thanks to diversification, the company was able to survive and positioned themselves against the automotive and medical industry instead. Today the company is focusing on expanding in the medical industry. The market for injection moulding is large enough at the moment at Frohe AB see no reason to implement AM further to receive any market shares. Frohe is one of the largest plastic manufacturers in the Stockholm region. (Samuelsson, 2016)

4.3.5.2 Marketing strategy

Frohe AB are focusing on sub-manufacturing in the nearby area where they feel that the market for medical products is growing and newcomers appear. The medical industry currently stands for around 70% of the company's business. Frohe AB can differentiate from their competitors through offering complementary methods as ultrasonic and laser welding which helps in the competitive industry. The company are in the midrange volume production where they prefer to manufacture products in intervals of one to two weeks. This means that the introduction rate of new products is high and stretch between 30-60 product introductions per year. The company are also interested in helping with the design phase of it is requested. (Samuelsson, 2016)

4.3.5.3 How do products win and qualify for orders in the marketplace?

Frohe AB wins' orders by commitment and closeness to their customers. They feel that these are the most important aspects and are the factors that eventually secure the orders. By also offering complementing methods, Frohe AB feels that they can qualify for orders when customers are looking for these services. (Samuelsson, 2016)

4.3.5.4 Process choice

The used manufacturing method is solely injection moulding for thermoplastic and silicon products. They also have their own desktop AM machine in-house but buy most of their AM produced units from other sources which are used as prototypes. (Samuelsson, 2016)

4.3.5.5 Infrastructure

As a pure injection moulding company the supporting processes are structured around that method. Because of belief that any large investment in AM are not needed in the near future, any change in the infrastructure will not be required. (Samuelsson, 2016)

4.3.5.6 Incentives to adopt additive manufacturing

Mårten Samuelsson believes that AM has future potential for competing in manufactured series up to 500 units/year. Samuelsson believes that the possibility to produce complex design that conventional methods as injection moulding cannot produce is where injection moulding will have an advantage. There is also potential in the spare part industry but he believes that current AM methods cannot produce products for that sort of applications. One other aspect that can push AM forward in the industry is the ability to reduce time to market. (Samuelsson, 2016)

One other area where the company have done investigations is to produce tools for injection moulding with AM but is currently just at the discussion stage. Samuelsson does not believe that the change in design processes if using AM would be any problem for the company. (Samuelsson, 2016)

4.3.5.7 Challenges to adopt additive manufacturing

Even though Samuelsson can see potential growth areas for AM he does not believe that it is a market they need to enter at the moment because of the satisfying position they have in the injection moulding industry. Samuelsson believes that one of the challenges with AM is the high investment. Samuelsson express that if you invest 2 million in a machine you have to have to know that you can get your money back. The parameters that needs to improve to for AM to get more market shares are surface finish, repetition accuracy and tolerances. (Samuelsson, 2016)

Even though Samuelsson says that there is not a project when AM is not involved for prototyping and testing, no customers have had any request for final production with injection moulding. But he also express that it would not be natural for them to have that discussion with them. When Samuelsson is asked about AM competing with injection moulding he says that he believes that he will be retired when that happens. (Samuelsson, 2016)

4.3.6 Case VI: Detus Formplast

Detus Formplast is a small company in the Stockholm region owned and operated by Urban Tomaszewski. The company was founded by his father in 1990 as a hobby project and has grown since his son took over. It is situated next to a company that manufactures swimming pools and is and has been the largest and most important customer for the company. (Tomaszewski, 2016)

4.3.6.1 Corporate objective

The corporate objective is to have a sustainable growth of 10 percent each year. The 10 percent growth is set to have a stabile expansion of the company while still not neglecting a high service level for their current customers. AM is not something that needs to be implemented in the company to reach this goal in the current market. (Tomaszewski, 2016)

4.3.6.2 Marketing strategy

The company is mainly a sub-contractor for injection moulded plastic parts. To keep a stabile position in the market, the aim is to diversify and receive customers from different industries. The current sectioning in the market have a strong direction against the swimming pool industry which have 40-45 percent of the orders. This market had earlier around 70 percent of the market and was lowered to decrease the risk and the goal is to have 30 percent eventually. Other industries that Detus are supplying are the medical industry, toys, giveaway products and the chemical industry. The standard orders that Detus receives are around 1000-5000 units/year but the company also have orders as high as 1 million a year and lower orders for 300 units/year. (Tomaszewski, 2016)

4.3.6.3 How do products win and qualify for orders in the market

The owner of Detus says that the price level is around the same for all of the companies in the injection moulding industry which means that other factor will have a more important role.

One way to win new orders for the company is by word of mouth from current customers. Much of the customer are driven by closeness to supplier which means that the company have some advantage to qualify customers in the nearby area. AM is only used as a service to customers. According to Tomaszewski, many of their customers choose them just because of the size of their company and the knowledge that they will receive a better customer service from them than from a larger company. So the price is more of an order qualifier and service and closeness to the customers are the order winners. (Tomaszewski, 2016)

4.3.6.4 Process choice

The company have five injection moulding machines which is their core business and two FDM machine for prototyping and design modification. The company have currently no plans to acquire any more AM machines. (Tomaszewski, 2016)

4.3.6.5 Infrastructure

As a small company, much of the responsibility is on the owner, Urban Tomaszewski's, shoulders who handles everything from machine operation to sales. If implementing injection moulding on a higher scale he says that new capabilities must be brought into the company. (Tomaszewski, 2016)

4.3.6.6 Incentives to adopt additive manufacturing

Tomaszewski can see advantages with AM technology for making prototypes and trying designs. One example is when one of their customer was going to develop a new pump for their swimming pools. Instead of ordering different sizes of expensive bronze pumps and waiting for them to be delivered, Detus could provide models with the help of AM which they could perform tests with. Tomaszewski said the mechanical properties was sufficient for the customers' assessment and the customer ended up with a finished design that they could use for the bronze mould. Tomaszewski is also surprised that there are not more companies that are using AM technology because of the value it can bring to the customers. He also says that the software programs for AM has improves a lot and will continue to advance. (Tomaszewski, 2016)

4.3.6.7 Challenges to adopt additive manufacturing

Tomaszewski believes that AM technologies are to slow for making longer production series but can be used for making single products and short series. If you can live with the reduction in material strength compared with other methods, AM technology can be valuable. Tomaszewski says that he does not think that buying a larger machine would be profitable because of the low utilization of the machine. He also expresses that the material cost for AM are too expensive and the jump to more industrial machines for better quality does not justify the price difference. He said that the price of the material is a stronger resistance factor than the size of the investment. If the price on the material was cheaper for Tomaszewski think they would invest in an industrial machine. One other challenge is that because of the many technologies for AM, it can take a long time to get acquainted with the different technique

and get the knowledge of what parts that can be printed for adding value. The problem with lack of material variation for AM is also brought up in the interview. (Tomaszewski, 2016)

Another aspect Tomaszewski brings up is that the product life time of most parts produced with injection moulding is 10-15 years or longer. Detus for example has one product that have been produced since 1955. Therefore, investment of the tool has been paid back a long time ago and the tool cost is close to zero. (Tomaszewski, 2016)

5 Analysis

In the fifth chapter the gathered information from the interviews, the survey and the literature will be analysed to identify the incentives and challenges there are for companies within the plastic industry to adopt AM technology. The first part of the analysis will be about what incentives that can be identified in this study and in the second part the challenges will be identified using the resistance model created by MacVaugh and Schiavone.

5.1 Incentives

The most important incentives are about the unique opportunities and advantages AM has. In this segment of the analysis chapter those advantages and opportunities that has come up in the case companies and the other sources will be analysed.

5.1.1 Mass customization

Mass customization is a unique advantage AM has in comparison to injection moulding. There is no need to build an expensive mould and the production can begin right after the 3D-model has been created. With the AM machines getting more efficient and cheaper there is an opportunity to mass customize products that before was standardized. In the case of Atos medical they were looking at the opportunity to customize a standardized high volume product to get advantage over their competitors by creating a high value for their customers while also tying the customers closer to the company. According to the gathered information from the surveys and the interview with Olaf Diegel this is something that is already used in the medical industry where every patient is unique and customized products is of much value. With the use of AM growing in the medical market, it can lead to other markets realising the value of tying customers to their products with the help of customisation with AM.

5.1.2 Prototyping

Even though prototyping is the most common application for 3D-printing and that it has become one of the most common methods of producing prototypes there is still large potential for further adoption. In the case companies there were still a few of them that did not own their own 3D-printer and instead they outsourced it to a prototype company. Tomaszewski from Detus have invested in a cheap desktop printer and was very satisfied with the opportunities it gave him to be able to provide prototypes for his customers. He also made a series of testing wheels for one of his customers, which created large value for a very low cost. Those kind of value creating services that can be created with even a very simple 3D-printed points towards that more and more companies will invest in these machines. The simple 3D-printers are so cheap that it is a very good way of familiarize with the technology and learn the possibilities with the technology and how to design in the best way possible. According to the company interviews, prototyping with AM will continue to be of great value and good way of learning the technology. If material properties increase, the use of prototyping within the companies might be a stepping stone for final production with AM due to that the experience already existing on the companies.

5.1.3 Spare parts

In spare parts production there is large potential to create value. In the interview with Rickard Nilsson from Tetra Pak, he brings up the possibilities for companies to improve their service level and lowering the need of keeping products in stock. In the case of Tetra Pak, they keep a lot of spare parts for old machines in stock that are no longer produced. With AM they would just need the 3D design and print it when it is needed instead of keeping it in stock. Another aspect is to lower lead times for the customers to get their spare parts. Time can be crucial when involving spare parts due to downtime in production can be expensive. With the use of AM and printing on location, the need for expensive solution to transport the products can be reduced. This in an aspect that Tetra Pak along with other companies are aware of. In this application AM can create large value by decentralizing the production and being closer to the customers. If larger companies as Tetra Pak implement AM for reducing stock for Spare Parts other companies may realise the potential and follow.

The potential of making spare parts is large for metal AM but it is difficult to tell how the potential is for plastic AM. Tetra Pak is only looking at metal AM for spare parts right now because the majority of their parts are made of metal.

5.1.4 Difficult products to manufacture

In the design phase of the product development process designers always face the trade-off between design attributes and manufacturability. With AM the product will always be able to be manufactured but to a higher cost. AM gives more freedom to the designers to design it just the way they want it with attributes that previously would have to be compromised for the sake of manufacturability. When AM is adopted more widely and accepted as a regular manufacturing method for products, designers will learn how to design in a way that exploits the benefits of AM technology. It is likely that there is a lot of products that could be designed in a better way but it is hard for the companies to change them once they have been introduced in the market. Lars Sickert says that a lot of their parts in their machines could be designed in better ways with AM. The problem is to audit all the products that already exist. Urban Tomaszewski brings up one problem with changing from injection moulding to AM. That is that the tool for injection moulding already exist and product life cycle is often 10-15 years or longer. That removes the cost saving of using AM instead of injection mouldings and then the change to AM is rather a cost of that the cycle time becomes lower. Therefore, the incentive to use AM for parts that can be designed in a more functional way is much stronger for new products than existing products.

5.1.5 Low volume products

Another potential area for AM are for low manufacturing series. This is already used by companies as Prototol PDS where volumes up to 1000 units are considered to be made with AM. To be considered, the product needs to have properties suitable for AM which gives them an advantage over standard production with injection moulding. The opinions regarding future volumes made with AM are very divided in the industry where some people see 1000 as

the upper limit while other believe that AM will compete with injection moulding in volumes up to 10 000. The reason for difficulties when approximating future volumes are that the size and geometry of the object are parameters that effect cost and printability and the level of future development and improvement for the technology are hard to foresee. To make the finished product competitive with existing products, material quality needs to be up to standard which is one of resistance factors in the industry today.

5.1.6 Ownership of the products

The focus group of this study is companies that use injection moulding. That group can be divided into two groups. Companies that design, market and produce their own products and companies that mainly produce products that other companies market and sell to the end customer. In this study Atos falls into the first category and the rest falls into the latter. However, all of the companies in the latter group also owns some of the products they produce. Those products they have developed themselves but they are still selling them to other companies that market them to the end customer. In Kanor for example, their own products stand for 50% of the total revenue. They use it as a part of their manufacturing strategy because their own products are made to stock while the other products are made to order. That means that they can produce their own products when they have free capacity and get better utilization of their machines.

It seems like the incentives are stronger for companies like Atos because they are more focused towards the need of the end customer. The utility and functionality of their products are more important than the production method, unlike companies in the other group that are given a job to produce a product in a certain way for a certain price. Therefore, the incentives will be stronger because the companies are more open towards new technology and features.

5.1.7 Corporate objectives and marketing strategy

In the information gathering with the Terry Hill's manufacturing strategy model, a similarity can be found in the corporate objectives, marketing strategy, order winners and the attitude toward adopting AM. In the cases of both Detus and Prototal PDS they have growth strategies and marketing strategies to reach a broad set of markets. They also focus on service and being a reliable contractor. They adopted 3D-printing to make prototypes and being able to offer it as an additional service that create extra value. Both these companies have also started producing products with AM and that has become a new business for them. Today it is not large but the tendency to be explorative as a company that has growth as an objective show that these types of companies are more likely to adopt AM.

Atos medical has a different objective but it has the same implications. They own their own products and their objective is to grow by entering new markets with their products and maintaining their strong market position. Their strong position in the market is defended by continuous product development and creating unique value for their customers. That is also a reason for them to look for new ways of making their products and they can see that AM can create that kind of value.

5.1.8 Order winners and qualifiers

When analysing the interviews, a consensus can be identified concerning order winner and qualifiers. Due to well established technology of injection moulding that have existed for a long time the price offered to customers has reached the same level for injection moulding companies. Many of the companies wins orders by offering additional services and by maintaining a good customer relationship. Closeness to customer also seem to be a factor that qualifies for orders. With the use of AM, additional services as design modification and prototyping can be simplified and are frequently used by companies in the plastic manufacturing industry. With a potential step towards manufacturing in small series, the companies can qualify for orders by offering an additional service through complex design solution for final production.

5.2 Resistance model

The analysis with the resistance model is divided by the three domains where resistance occurs according to MacVaugh and Schiavone. In these three domains; Individual, community of users and market/industry the resistance factors are categorized according to the three different types of resistance factors introduced by the creators of the model. These resistance factors are technological factors, social structure and learning factors.

5.2.1 Individual domain

In the individual domain the focus is to look at what aspects that is increasing resistance to adoption within the individuals, which in this case is the interviewed companies. What internal challenges they have to adopt the technology and if there are similarities between the companies in what internal aspects that are most important.

5.2.2 Technology

The factors that has to do with the utility of the technology is primarily the cycle time, surface finish and the strength of the product. These factors are often linked to a certain AM process, for example, the surface finish is often one the resistance factors linked to SLS while SLA is better in this area. SLA on the other hand has problem with the strength while SLS has very good strength. What this means is that the individual companies must make a decision of what they would like to use the technology for and what properties that are preferred for their products.

Depending on what the companies want to use the technology for they will choose the process that fits their purpose. That is an important resistance factor when it comes to a company like Prototal PDS, whose market strategy is to be able to serve a broad range of customers with different needs. Other companies have to choose which process that fit them best which can be a difficult choice because of the lack of experience that can exist for what the different processes can provide and what capabilities that are needed for respective technology. This relates to the strategy for some of interviewed companies that wants to be able to produce a variety of products. To provide this, multiple AM technologies have been implemented in the

production which increase the investment cost for adopting the technology. For a company like Atos it is different because they will only use it for the applications that they need for their own products, which means that they probably only would need one type of process.

A utility factor that all processes has in common is the long cycle time. That is the main resistance factor for a lot of applications the plastic industry because it often competes with injection moulding which has a very short cycle time. For manufacturing of longer series, the cycle time is a trade off with the lead time of the injection moulding tool.

5.2.2.1 Social structure

For the companies that work with subcontract manufacturing with injection moulding, the internal incentives for adopting AM are not strong enough. The contagion effect from customers will instead be a more important aspect for the adoption in these companies. The knowledge and incentives for their customers to ask for additive manufactured products will be the important factor that affect the rate of adoption.

The companies in the focus group are often very oriented towards the old technology. A lot of that can be explained by the tough competition in the market. They are competing with other companies that have similar capabilities and sometimes the order winner can be the geographic location or that they are reliable in their order delivery. This is making the companies to have a more reactive strategy than pro-active. So they tend to look at AM as a technology that can affect their business in the future but not as something they could adopt to get a competitive advantage. The exception was the case of Prototal PDS that was a bit different because they started with AM early to make prototypes and could now see that they could benefit from the technology by providing an extra service for their customers.

In the focus group of plastic companies there is a lot of knowledge about plastic manufacturing and plastic materials. This can be seen as an advantage for them but it seems like even though the interest for the technology is high and the attitudes toward it generally is positive they do not see it as being relevant to them. A reason for this might be that AM technology do not compete with one single manufacturing method but with almost all of them. However, AM technology may not be a threat to the other methods when comparing them one against the other but a manufacturing method that will take a little market share from all of them. Combined it will constitute a market opportunity for the plastic companies. This may create a resistance factor because plastic manufacturers have to change their market strategy to exploit the business opportunity.

5.2.2.2 Learning

Something that is coming up in every interview with the case companies and also in the survey is the design process. It seems like the design process is a vital part of adopting AM technology because of the fact that the products have to be designed in a way that they exploit the advantages with the technology. In the case of Atos, they develop and design their own

products and that seems to be the main reason that they see what advantage that AM technology can give them and how that can increase their competitiveness.

In some of the cases they have sub-contracting manufacturing, which means that they do not own the product and only helps with the manufacturability of the design. That creates a strong orientation towards the manufacturing methods that they currently have and they try to design it to suit injection moulding.

The cost relating to adopting AM depends on what kind of printer that is purchased. For a small company like Kanor or Detus an investment in a printer for industrial purpose, the investment is very high. Detus invested in a small desktop printer, which they could use to create an extra service for their customers and when their printer was not able to reach the standards required they bought the service from another company. For their purposes a desktop printer was good enough. When it comes to industrial sized printers with higher productivity it is not only the investment that is higher. The material for the industrial printers are also higher, which was an important resistance factor for Detus who said that they would invest in an industrial printer if the material was cheaper.

5.2.3 Community of users

In the domain of the community of users the focus is on aspects that might not be an important resistance factor for the individual company but for the group of companies as a whole it becomes a problem.

5.2.3.1 Technology

An aspect that has been mentioned very often is the lack of material. From the cases and the surveys, it is clear that the lack of different materials restrict the use of the technology. It is not the most important for the companies but in the interviews they mention that it is something that would be good to improve. However, in the survey it is a topic that is brought up as a very important aspect. The fact that the representatives from the 3D-printing industry report that material development is the higher prioritized than machine development points out that it is a resistance factor today. A few of the interviewed companies say that their customers often want to produce the products in a certain material. If that material does not exist, they reject 3D-printing even if there is a material that has similar properties. When comparing the amount of different materials available for injection moulding in comparison with the amount of material there is for AM it is a large difference. As a group, plastic companies are used to be able to choose from a wide range of different materials which is more restricted when using AM technologies.

In addition to that there are less materials available for AM technology there is also not the same materials as in other manufacturing methods. There are some materials that cannot be

used in AM but instead materials that emulate the properties of these materials, for example polypropylene.

Reparability of the machine is an aspect that can be important for the adoption of AM in the group of plastic manufacturers. In this group operational efficiency is a high priority and the cost competition is high. For example, the informants at Detus and Frohe says that all the injection moulding companies basically have the same prices and they are instead competing with service. To be able to integrate AM in this group of users and replace injection moulding for longer series the reliability and service of the machines is an important factor.

5.2.3.2 Social structure

In the community of users there are tendencies of orientation towards the old technology and focus on operational excellency instead of new technology and investment. The hard competition in the market for injection moulding companies creates a strong focus on lowering costs and keeping the return on investment high. Competition from china has taken away larger volumes so companies in Sweden focus a lot on reliable quick delivery and quality as well as producing lower volumes for good prices.

As stated in subsection 5.1.6 there are two distinctly different types of companies in the community of users that this study focuses on. Companies that develop, market and sell their own products and companies that are subcontractors to those who market and sell the products to the end user. In the latter group there is less focus on looking for new ways to create value for the end customers because they listen more to the needs of their own primary customers. Therefore, it will be riskier for them to implement AM because it is dependent on that there is a need for that service in the markets they are active. Otherwise they would need to implement AM and use a different business model for that business area. That would require another marketing strategy to attract new customers.

5.2.3.3 Learning

As mentioned in the previous chapters one of the most important processes for implementing AM technology is the design/construction processes. The design/construction departments have a vital role to play for the companies to be able to exploit the advantages with AM technology and it is there the largest knowledge gap exist. In the companies, there was very little knowledge about how to design for AM and also other sources admits that the knowledge and capabilities within companies in the plastic industry are very low.

Most of the companies replied that they get knowledge about new manufacturing technology and developments in the industry from industry magazines and exhibitions. In these channels today there is a lot of focus on 3D-printing and it is a part of the hype around the technology. The knowledge will probably improve continuously and companies will get more interested in investing in a desktop machine to try the technology. That is what Detus did for example.

5.2.4 Market/Industry

In the market/industry domain the analysis will focus on the factors that affect the manufacturing industry as a whole.

5.2.4.1 Technology

In the interviews and the survey, it seems like there is a consensus about that the technology have a large potential. There also seems to be a consensus about that metal AM has more potential when it comes to manufacturing and plastic AM is still more for prototyping. Very small volumes are already being produced in plastic AM but there is no consensus about what the volumes are going to look like in the future. There is no clear answer of who are going to use AM for producing larger volumes because the result in the interviews show that the focus group are reluctant to adopt the technology for that purpose. Also for using it in house for their own products like Atos that say that they might outsource the production. Tetra Pak also say that they do not know if they will produce in house or outsource. The applications where there is potential for AM is fragmented across the manufacturing industry, which may create a need for AM specialized manufacturing companies but the industry in Sweden is not there today.

Standardization is a resistance factor for the industry in general. The companies want to know that they can get the materials they want without having to buy a certain machine and that the processes are reliable. Standardization is also an enabling condition for the ability to automatize and standardize processes, which is an important factor for companies in the focus group for this thesis. The reason is that companies that use injection moulding have highly automatized processes and standardized ways of working.

5.2.4.2 Social structure

In the manufacturing industry the large companies like Volvo, general electric, Siemens or Boeing has large power both as opinion leaders and as customers for smaller sub-contractors. A lot of those companies have started adopting the technology and that is a start for broader adoption across the industry.

Another aspect that has been highlighted is that AM technology will not replace any manufacturing method completely, but it will instead replace some activities in multiple manufacturing methods. Therefore, AM will be a complement and an addition in a lot of different fields and in different applications. For example, at Tetra Pak it has the potential to be used to produce some of the parts and some of the spare parts. The problem with that is that the technology has potential across so many departments and applications is that it might be hard to see the total utility of the technology in the company. It might also mean that it requires a lot of work and investment to exploit the full potential of the technology. It will also require cooperation across functions in large companies and with external partners.

Today large companies like Boeing and Siemens are adopting mainly metal AM and in the interviews with Tetra Pak it is also metal that is the first priority. Mainly that is because their

machines contain mostly metal parts, however the savings in material cost, the increased heat resistance, lower weight and better mechanical properties due to consolidated parts constitutes very strong incentives for investment. The incentives are not as strong in plastic manufacturing so maybe the larger future investments in metal AM will have a push away effect on plastic AM. Another argument for that case is that many companies already have invested in plastic printers for prototyping and may see metal as the next step instead of a more industrial suited plastic printer.

5.2.4.3 Learning

The recent year's hype around AM technology has improved the awareness and the knowledge about the technology. That is definitely a factor that increases the rate of adoption but there is a need in the industry for more knowledge about how to design in a way to exploit the advantages that AM technology has. The price of desktop printers has decreased a lot the recent years, which will make it easier for companies to invest in printers for the design and development departments to use for experimenting and familiarizing themselves with the technology. It seems like there is a consensus that there is a need for people that know how to design for AM and that the technical universities and other educational institutions in Sweden are lagging in this.

6 Summary and conclusions

In the sixth chapter the most important points from the analysis is summarized and the implications of the results are elaborated with and put in a wider perspective.

6.1 What are the major incentives?

The major incentives for companies to adopt AM is the unique possibilities there are with the technology. The major incentives that is unique for AM in comparison with other manufacturing methods are short lead time, no tool investment needed, ability to decentralize production, reducing material waste and possibility of mass customization.

These incentives create opportunities for companies to solve technical problems that could not be solved before, business opportunities to create customized products competitively, produce and distribute products in a faster and less resource demanding way. Today the machines and materials are developing quickly and AM technology have entered the market for manufacturing applications. When the productivity of the machines and the availability of a broader range of materials are increasing the incentives of using AM for manufacturing applications will get stronger. The cost of materials will also be a factor when it comes to how large the volumes that will be economically beneficial.

6.2 What are the major challenges?

If AM technology is going to be adopted on a broad level in the plastic industry there are some challenges that are important to recognize. How these challenges will affect the rate of adoption and how AM will be used in the future is very uncertain but it increases the understanding of how the AM industry will develop in the future. The most important resistance factors that were found in this study were utility factors such as long cycle time, build area and quality, but also that design capabilities are lacking in the companies, the applications that fit the technology are fragmented across industries and there is a lack of available materials. There is also a lack of experience in the industry of how AM best is utilized and for what products the technology is applicable and beneficial.

6.2.1 How is the plastic industry going to adopt AM?

The purpose of this study was to see what incentives and challenges there are for companies in the plastic manufacturing industry to adopt AM. The results from the research produces a view of how AM will be adopted in the plastic manufacturing industry. This study focuses on existing companies that uses injection moulding and if it is a possibility that AM will be capitalized on by these types of companies. They have knowledge about the materials, they have existing customers that can benefit from the technology and they have knowledge about what needs and demands of the customers. Therefore, it is likely that established companies will try to capitalize on this new business, which already have started today.

Rapid prototyping is already today an established application for AM, but it is today more common to outsource the production of prototypes to specialised companies. These companies are probably going to take some of the market share in the future but plastic companies are likely to also take part in the market because they already have a relationship with the customers that design the products or they design the products themselves and produce in house. It seems likely that a majority of the companies in the plastic industry will have at least a desktop printer to make simple prototypes within a near future. When it comes to industrial type manufacturing for higher volumes it is harder to tell and maybe it will be divided between general plastic companies that adopt it as another manufacturing method or specialised companies that use it as their core competence.

7 Reflections

The seventh chapter will discuss the structure for the working process of the master thesis. The companies involved will be discussed as well as other information sources. The challenges that have appeared will be evaluated and in what way they have had an effect on the produced results. Reflection concerning future research and contribution and general and academic contribution will also be included in this chapter.

7.1 Working Process

The AM technology has been around since the 80s which means that the companies involved in this study is familiar with the technology and its capabilities. What has been noted by many of the companies is the hype that exist around the technology and that the potential for the AM method sometimes seems too good to be true. When getting more acquainted with AM, the companies have been able to get their own opinion regarding the technology and what restrictions and incentives that exist for their businesses. The focus seems to be centred on the existing AM technologies and what can be developed to improve the machine's capabilities and the material properties. Even though new technologies appear, the well-established technologies seem to gain the most attention. The reason behind that can be the strong market position of the 3D companies that has been around since the 80s and 90s.

When approaching companies in the plastic industry with the AM subject in mind they seem to have an open mind and a genuine interest in the technology. As mentioned before, the companies are already familiar with the technology so what often wakes their interest are the future potential of the technology and new applications areas. It can be for one of their own products, as it was in Atos Medical's case, or for offering customers new services and production option. The interest from the companies has led to many valuable discussion during the interviews about AM and what they believe is the future potential. Often these conversation has led away from the companies own interest and instead what can be done with the technology for the whole industry in the future. This has been welcomed for the master thesis due to one of the objectives was to identify resistance factors for the industry.

When speaking about the incentives and challenges for their own use of AM technology the answers has been more divided. All of the companies agree that the current application areas as prototyping and evaluating designs are appropriate with the current standard of the technology. What divides them is the new application areas and if AM can be used for making end user products. This has much to do with the demand from customers due to most of the companies are sub-contracting companies adapting to customer specifications. That means that until requested, further research of application areas is not a necessity. When reflecting back on the company selection, this is an aspect that could have needed more attention. Instead of having the majority of the companies being subcontractors, a larger part of the study could have included companies that meant to use AM for their own products.

Reflecting back on the working process much of the progress have been reached through extensive market research in the beginning of the process. To get the most out of the interviews it is important to have knowledge in the area discussed to complement the standard questionnaire with follow up questions.

Another aspect that has been valuable for the thesis is the complementary sources that have been used to receive further depth of the subject. During the process the authors have visited Nordic plastics fair and Swerea in Mölndal. The collection of companies participating in the plastic fair meant that the key question of the thesis could be further evaluated based on the expertise from actors in the additive manufacturing industry and from plastic manufacturing companies. The Nordic Plastic fair was also used as a platform for company connections when conducting the survey research. The visit at Swerea, who is a Swedish research group, was executed in the late phase of the process and was therefore used to verify the information gathered.

7.2 Academic contribution

Additive manufacturing is already a well-established technology known in the plastic manufacturing industry. It has established itself as one of the most common ways of making prototypes and it has started to enter the manufacturing segment. The approach for this thesis was to further go in to depth in the technology implementation within the plastic manufacturing industry to evaluate their perspective of incentive and restriction of using the technology. The models that are used in the thesis is the Hill's framework for manufacturing strategy and the resistance model created by MacVaugh and Schiavone. The academic contribution in this thesis is how to investigate factors affecting the adoption of manufacturing technology by combining theory from the fields of manufacturing strategy and innovation theory. Research in the field of technology adoption is to a large extent focused on the consumer market so it was needed to combine innovation theory with theory in manufacturing strategy.

7.3 General contribution

Outside of the academic world this thesis can be used to understand the difficulties there are for a manufacturing technology to be adopted on a broad scale. As mentioned in the introduction there are nine technologies that together are called industry 4.0 and are expected to transform manufacturing in a disruptive way. What these technologies have in common is that they have the potential of being adopted in all types of industries and they are driven by a technology push rather than a market pull. What this thesis can contribute with is an understanding of the incentives and challenges there are in the adoption of a new technology where the market is driven by the technological development. The difficulty is to see the value of the technology and overcome the challenges there are with integrating the new technology in the current manufacturing strategy.

As a technology used in other markets than plastics manufacturing, AM has other application areas that are not evaluated in this thesis. The focus on companies in the plastic industry means that certain trends can be noticed that can be applicable for other industries as well. A lot of the conclusions in this thesis can be applied for example in the adoption of metal AM.

This thesis also gives a picture of what challenges the AM industry is facing and how that market will evolve in the future. A lot of the challenges with adopting AM in the manufacturing industry must be met with further development in machine technology and material development in the market. The market still has a long way to go before maturity and there are a lot of commercial possibilities for companies that still haven't entered the AM market.

7.4 Further research

This study focuses on applications for AM in the industry and does not investigate the diffusion process of consumer 3D-printing. The processes are different in many ways but they also have a lot in common and they affect each other. Today consumer 3D-printing is growing and companies like Formlabs and Makerbot have developed the market for desktop printers. These are cheaper and the material also cost less making it a low investment to test the technology and learn of the possibilities with it.

New business models might also arise with the availability of cheap desktop printers. 3D-printing hubs is a model like that where a person with a printer can list herself at a website and print on demand for people in the nearby area (3D Hubs B.V). This is an idea about the decentralized production system where people can print products on demand without the need for transportation. There are some issues regarding this phenomenon that would be interesting for further research. The issue of intellectual property will be interesting because the importance of the design stage in the value chain will increase when the manufacturing is decentralized closer to the customers. Another issue is what kind of products that would be suiting for this type of production. Today the expectations are very high on the effects of the economy if 3D-printing would change the supply chains in a disruptive way but it is very hard to say which types of products that can or will be produced this way. A third issue is the repeatability and the standardization of the 3D-printing machines. In a networked society the value of a product increases if more people use the same product. This rule will to some extent apply to a network of 3D-printers because the availability and closeness will be the factors that increase the value of the network. Also complementary services like designs and materials will increase in quality and availability when there are more users.

An important aspect of decentralized production is the repeatability of the printing process which requires that the same machines is used, the same way with the same material. If the repeatability is uncertain it will be hard for both consumers and companies to rely on this model. Standardization of methods and materials can be a way of increasing repeatability and reliability of this model. The possibility of standardization within the AM industry would also be an interesting topic for further research.

Other topics that would be interesting for further research are the value of time to market and the need of capabilities within designing for AM. The value of time to market would be interesting because that is one of the strongest advantages of AM and it would be interesting to investigate what the value of a short time to market is in different industries and if that can weigh up the disadvantages of AM processes. Design capabilities is one of the factors of resistance that is seen at a lot of the individual companies but also a factor that is brought up as a general resistance factor on an industry level. It would be interesting to further research how universities can work together with the private sector to increase the capabilities needed to enable a broader diffusion of AM.

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Appendix

Appendix 1: Standard questionnaire for the case companies

Introduction

- Short introduction of the interviewers and the purpose of the thesis.
- Introduction about the content of the interview.
- Ask if it is ok to record the interview.
- If there is anything the interviewee want off the record, that is ok.
- Tell us about yourself and the company.

Current situation

- What are your corporate objectives?
 - Growth, Survival, Profit etc.
- Can you tell us about your marketing strategy?
 - Leader vs follower, range, standardization vs customization
- What is your operations strategy?
 - Cost focused, agility etc.
- What are the order winners and order qualifiers for you?
 - Price quality, design etc.
- What production method do you currently use?
 - Injection Moulding etc.
- What different manufacturing processes do you use?
 - Job, Batch, line etc.
- What different product do you manufacture?
 - Design?
 - Cost per unit?
- How is the competition in the market?
 - Cost competition?
 - Technology competition? Is customization a factor?
 - High margins?
 - Investment possibilities?
 - Responsive? Agility?
- What volumes do you have generally? Is it large differences between products?
- Why have you chosen your process choice, manufacturing method?
- What supporting functions do you have for your process choice?
 - ERP, Integrated functions, communication etc.
- Where is your order decoupling point?
 - Make to order or make to stock?
- How often do you introduce new products?

- What is your current time to market on your products?
- What polymer material do you use in your production?

Questions about additive manufacturing

- What do you know about 3D-printing?
- What do you think you can use 3D-printing for?
- How can you integrate the technology in your production process?
- What is the competing manufacturing process?
- What are the main drawbacks with the current technology? How does it restrict you?
- Do you see 3D-printing as a future main manufacturing method or as a complement?
- What are the main advantages for you with 3D-printing?
- What are the drawbacks with 3D-printing?
- What is your personal attitude towards 3D-printing?
- How do you get information about new technologies?
- What are the attitudes towards 3D-printing in your industry?
- What do you believe the trade-offs would be if implementing AM?
- Is time to market an important factor for your product development?
- What is the main thing that 3D-printing has to deliver?
 - Cost advantage, customization, properties, resolution, surface quality, cycle time, reduce material waste etc.
- If the technology would have the same total cost. Would you consider using it?
- What knowledge/capabilities do you need for the implementation of 3D-printing?
 - How do you think the design process would change?
 - Do you think that the post processes would be a challenge for AM?
 - Do you believe that the operation organization structure would need to change much from the current one?
 - Do you think there will be a lot of time spent on Educating staff?
 - What supporting function do you think you have to establish?
- Do you think there would be an interest in the organization to invest in a trial period where the technology is tested on a small scale?
- Do you see a market for 3D-printing products/services and do you think that you could capitalize on that?
- What are the attitudes towards investments in manufacturing technology in the organisation? High priority?
- How do you think the technology development will change the plastic industry in the next 10 years?
- Do you have any products in mind that you think would be suitable to produce with 3D-printing?
 - If yes, what is it with that product that makes it suitable?
 - Do you have new products in mind that is suitable for 3D-printing?

Material

- What material properties are most important to you?
- How important is availability of different materials to you?
- What is your current material cost?
- What material cost would you expect when considering implementing AM?

Appendix 2: Qualitative survey

1. Which are the largest constraints today with AM technology?
2. How do you think the technology will develop the next ten years?
 - a. Material development?
 - b. Machine development?
3. In which areas within the plastic industry do you think AM have a potential future?
4. Do you think AM will be used for serial production in the future and challenge the conventional methods?
 - a. Which volumes do you think it will be in that case?
 - b. Which AM technology will be used?
5. How do you think the AM companies will work with R&D in the future? In house R&D, partnerships, joint ventures etc.
6. Do you think all material will be sold through the machine companies or will the machine companies certify material developers that can sell it themselves?
7. Where is the largest potential for material development? Powder, liquid photopolymer or filament?
8. Which AM technology having the largest commercial potential?
9. Do you have any further aspects you think is important for the future developments in the AM market?