Remanufacturing Versus New Acquisition of Production Equipment: Definitions and Decision-making Checklist

Master thesis work
30 credits, Advanced level

Product and process development
Production and Logistics

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ABSTRACT

With technology changing at a dramatic pace, entrepreneurs may assume that acquiring the newest production equipment available is the best option. But that is not always the case. It is important to first assess the needs in order to decide whether new or remanufactured production equipment is the best alternative. Investment on production equipment can be initiated due to existing equipment cannot handle capacity; products evolve and changes needed to meet market requirement; to continuously improve production system; or the general requirements for quality, environment, economy and safety. However, the study reveals that it has received only limited attention from academics and practitioners regarding to whether decide to remanufacture or new acquire production equipment. Further, the framework visualizes the complexity of managing decision-making between production equipment remanufacturing and new acquisition.

The study employs qualitative method by conducting literature review, interviews, brainstorming sessions, benchmarking, and observation to build the theoretical framework and collect empirical data. The thesis identifies the differences between production equipment remanufacturing and new acquisition; distinguishes the different levels of production equipment, proposes a new definition of production equipment remanufacturing; and analyses factors should be considered for the decision-making process. Altogether, the findings provide strong evidence to propose a decision-making checklist in decisions between production equipment remanufacturing and new acquisition.

(Keywords: production equipment remanufacturing, production equipment acquisition, Machine tool, updating, replacement, decision-making checklist)
ACKNOWLEDGEMENTS

It gives me great pleasure in expressing my gratitude to all those people who have supported me and had their contributions in making this thesis possible. First and foremost, I must acknowledge and thank my company supervisor, Dr. Marcus Bengtsson at Volvo CE. His broad spectrums of industry experiences and deep academic knowledge have been extremely beneficial for me. He has given me enough freedom during the thesis work, and he has always been so nice to me. I will always remember that he came to me every Monday and had “reporting status” meeting with me from week 4 to week 22. He always gave me the perfect answer of every question I asked. Thank you so much, Marcus. Without your guidance and persistent help this thesis would not have been possible.

I would like to express my gratitude to my university supervisor, Dr. Jessica Bruch for the great comments, remarks and engagement through the learning process of this master thesis. I express my deepest gratitude to Volvo CE, and in particular to Andreas Bander that gave me this precious opportunity to conduct the thesis. I have been around with extremely talented and hardworking colleagues at Volvo CE; they inspired, motivated, and positively influenced me.

Finally, I would like to thank my husband, Albin Malmqvist, who kept saying “skriva!” to me every weekend.
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<th>Description</th>
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<tbody>
<tr>
<td>OEM</td>
<td>Original Equipment Manufacturer</td>
</tr>
<tr>
<td>LCC</td>
<td>Life Cycle Costs</td>
</tr>
<tr>
<td>CNC</td>
<td>Computer Numerical Control</td>
</tr>
<tr>
<td>PC</td>
<td>Personal Computer</td>
</tr>
<tr>
<td>CIRP</td>
<td>International Academy of Production Engineering</td>
</tr>
<tr>
<td>VCE</td>
<td>Volvo Construction Equipment</td>
</tr>
<tr>
<td>VPS</td>
<td>Volvo Production System</td>
</tr>
<tr>
<td>TPS</td>
<td>Toyota Production System</td>
</tr>
<tr>
<td>OEE</td>
<td>Overall Equipment Effectiveness</td>
</tr>
<tr>
<td>MTBF</td>
<td>Mean Time Between Failure</td>
</tr>
<tr>
<td>MTTR</td>
<td>Mean Time To Repair</td>
</tr>
<tr>
<td>IRR</td>
<td>Internal Rate of Return</td>
</tr>
<tr>
<td>NPV</td>
<td>Net Present Value</td>
</tr>
<tr>
<td>CE marking</td>
<td>Conformité Européenne marking</td>
</tr>
<tr>
<td>PESTEL</td>
<td>Political, Economical, Societal, Technical, Environmental and Legal</td>
</tr>
<tr>
<td>MSEK</td>
<td>Million Swedish Kronor</td>
</tr>
</tbody>
</table>
1 INTRODUCTION

The first chapter of this thesis establishes the importance of the research area – production equipment remanufacturing and new acquisition. Based on a need for a more efficient decision-making approach of remanufacturing versus new acquisition, the research purpose is defined and the research questions are formulated. Further, the delimitation of the thesis is presented.

1.1 Background

With ever-increasing global competition, all manufacturing organizations are aspiring to have more reliable and robust production systems to increase the productivity and overall efficiency of their production lines. To be able to maintain and develop the ability to compete on a global market, manufacturing companies need to be successful in developing innovative and high-quality products with short lead-times, as well as designing robust and flexible production systems implying the best preconditions for operational excellence to meet the customer demand (Bellgran and Säfsten, 2010; Bruch, 2012). The delay of introducing the products to the market could give a negative impact on profitability of companies. Manufacturing companies may lose the first-mover advantage in the market, and the revenues of companies will decline (Hendricks and Singhal, 2008). Thus, businesses have to position themselves against their competitors by using appropriate strategies to better focus on customers and markets. Manufacturing companies are aiming to increase productivity, eliminate waste and at the same time, the pressure on business is growing to keep costs under control and even reduce them (Janz and Sihn, 2005; Moubray, 1997).

Meanwhile, environmental friendly issues are rapidly becoming one of the most important issues in production system (Azzone and Noci, 1998). The requirements from the customers, stakeholders and government to be more environmentally responsible are increasing; therefore, the production managers consider the improvements in environmental performance as one of the basic competitive priorities (Rusinko, 2007; Azzone and Noci, 1998). This green trend is encouraging industries to implement environmental practices such as reducing original raw material usage, reducing waste material, reducing energy consumption, improving and maximizing remanufacturing, recycling and other forms of recovery of wastes from end-of-life products and equipment (Du and Li, 2014; Örsdemir et al., 2014).

In production systems, reliable production equipment leads to meet the industry’s multiple demands for integration, flexibility, cycle time, and quality as well as it can have strategic implication for manufacturers (Deshpande, 2013). At the same time, production equipment in the manufacturing sector is the main source of energy consumption and carbon emission (Steinhilper, 1998; Du and Li, 2014). According to Aronson (2003), a manufacturing company needs remanufacture or acquire production equipment either because the current equipment is having problems or they need to expand to meet growing production requirements. It is important to improve machinery performance over the whole life cycle, which means to not only consider the acquisition costs for production equipment, but also considering the costs for running, repairing, overhaul, remanufacturing, replacement or disposing of it (Janz and Sihn, 2005; Enparantza et al., 2006; Baskakova et al., 2008; Aronson, 2003).

With the excess consumption of resources and optimizing maintenance costs, remanufacturing of production equipment is paid more and more attention for its enormous economic and social benefits (Du and Li, 2014). Du et al. (2012) state that among all kinds of machines, production equipment has a great recycling value and potential for remanufacturing. Previous literature
(e.g. Du and Li, 2014; Marsek, 2003; Du et al., 2012) indicate that production equipment remanufacturing has appeared in machinery companies for many years and achieved good results in developed countries, such as U.S.A and Germany. Matsumoto and Umeda (2011) state that in Japan remanufacturing industry grows rapidly which is driven by the regulations, subsidies, the environmental pressure and the market. In addition, Korugan et al. (2013) state that 33% of remanufacturing activities is done in the automotive industry. Further, in developing countries, such as China and India, production equipment remanufacturing has also gained more and more attention from the government, the manufacturing industry and the academic field (Du and Li, 2014; Rathore et al., 2011). Summing up, production equipment remanufacturing has developed rapidly in recent years, with the motivations from economic benefits, environmental legislations, and the growing environmental awareness of the customers and manufactures.

From the perspective of life cycle of production equipment, the economic and environmental benefits of production equipment remanufacturing are great (Du and Li, 2014, Zhan et al., 2006). For example, Östlin et al. (2009) claim that the life cycle of production equipment and the disposal rate have a great impact on the possibility to perform profitable remanufacturing. Though production equipment remanufacturing, it is possible to extend the life cycle of equipment or even a new life cycle is given. In fact, a recent study shows that the energy efficiency improved 10%-20% approximately by conducting production equipment remanufacturing (Du and Li, 2014). Instead of making a new acquisition of production equipment and disposing of old production equipment, remanufacturing is possible to reduce resource consumption, and waste generation. Du and Li (2014) conduct a case study in Chongqing, China. It shows that the energy can be saved by over 80% through production equipment remanufacturing in comparison with a new one.

1.2 Problem formulation

Production equipment remanufacturing is one of the categories under product remanufacturing. According to Lund (1983), the scope of product remanufacturing has been analyzed in different market segment in industry filed, which is automotive sector and industrial sector.

- Automotive: including automobiles, trucks, buses, motorcycles and parts.
- Machinery: all forms of machinery or equipment used in manufacturing.

Previous literature (Wells and Seits, 2004; Saavedra et al., 2013; Steinhilper 1998; Zhang et al., 2011; Stewart, 1998; Seitz and Well, 2006) indicate that research of remanufacturing in the automotive sector undoubtedly has been the main industry driving so far (Steinhilper, 1998). At machinery sector, many studies have acknowledged variable problems of production equipment remanufacturing from Original Equipment Manufacturers (OEMs) and the third party remanufactures perspectives (Du et al., 2012; Du and Li, 2014; Ferguson et al., 2009). There exist only a few studies focusing on production equipment owners’ aspects. In addition, some of the literature reveals remanufacturing for special kinds of production equipment (Zhan et al., 2006; Hayashi et al., 2013) instead of placing a general overview of production equipment.

During the entire life length of production equipment, production equipment undergoes several changes. These changes are not only based on performance, age, or number of failure, but also due to a number of external factors including new product introductions, new customer requirements, new production technology etc. (Kosiuczenko, 2012; Marais, 2013). Investigations reveal that the complexity and possibility of production equipment
remanufacturing is not well studied. Marsek (2003) claims that, every day, corporations underestimate the complexity of major remanufacturing projects. People assume that these jobs are the same as new production equipment acquisition.

Failure of production equipment may cost a lot of money to users in term of down time and lost quality. Once production equipment has been designed, its inherent reliability is fixed. It is the maintenance that then determines the profitability in the long term (Lad and Kulkarni, 2012). However, Du and Li (2014) reveal that there is a great amount of the production equipment that was produced in the 1970s-1980s is still in operation in manufacturing companies. With increasing demands from the customers, a large amount of production equipment cannot meet the requirements of workshop operation and they are facing these problems: adapting to new technology, shortage of spare parts, powering wasting, system aging, and needing remanufacturing (Zhan et al., 2006; Du and Li, 2014). Thus, daily maintenance routine cannot solve all the problems. Manufacturing companies need to have different options to consider for improving production efficiency or expanding capacity beyond maintenance. In upgrading the basic production equipment, one problem is to make intelligent choices among available options, i.e. to remanufacture, or to acquire new production equipment (Baskakova et al., 2008; Marais, 2013).

Production equipment repair strategies and repair maintenance policies have been explored by previous literature (Marais, 2013; Baskakova et al., 2008; Ijomah et al., 2007; Gray and Charter, 2008). The methods to determine optimal replacement time for production equipment is also presented by previous literature (MaeMillan and Meshulach, 1983; Golmakani and Fattahipour, 2011; Vujic et al., 2010). Further, the methods for evaluating the remanufacturability of existing production equipment are also presented in the academic field (Du et al., 2012; Bras and Hammond, 1996; Amezquita et al., 1995; Yoruk, 2004; Subramanian et al., 2009). Remanufacturing process and new acquisition process of production equipment are also proposed by literature (e.g. Bruch, 2012; Östlin, 2008; Sjödin and Eriksson 2010; Baskakova et al., 2008; Saavedra et al., 2013; Subramoniam et al., 2013). Thus, researchers are focusing on the processes before and after of the decision-making checklist.

The task of designing and building a decision-making checklist for remanufacturing or new acquisition is rather complex and often involves collaboration between operation department and purchasing department in a manufacturing company. However, the available research of how to make a strategy for decision-making for production equipment remanufacturing or new acquisition is still limited (Subramaniam et al., 2013), see Figure 1. Therefore, in the thesis the research of definitions and decision-making approach of production equipment versus new acquisition is carried on.
1.3 Purpose and Research questions

The problem description indicates that there is a need for additional research within the area of production equipment remanufacturing and new acquisition. Therefore, the thesis is giving the following purpose:

The purpose of this thesis is to propose a decision-making checklist in decisions between remanufacturing and new acquisition of production equipment.

Based on the purpose of the thesis and the problem description, three research questions have been identified during the course of this study.

**RQ1**: What are the differences between production equipment remanufacturing and new acquisition?

**RQ2**: What different levels of remanufacturing of production equipment can be identified?

**RQ3**: What factors should be considered and analyzed for the decision-making checklist between remanufacturing and new acquisition of production equipment?

1.4 Project limitations

In the thesis, the research object is treated in relation to physical asset, which is production equipment in manufacturing industry. Specific product, facility, vehicle, office material, software and service are excluded. A decision-making checklist will be proposed for remanufacturing versus new acquisition of production equipment that is based on both

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**Figure 1: Problem description of the thesis.**

<table>
<thead>
<tr>
<th>Repair Strategies and repair maintenance policies</th>
<th>Methods for evaluating the remanufacturability</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mariaš (2013); Baskakova et al. (2008); Ijomah et al. (2007); Gray and Charter (2006).</td>
<td>Do et al. (2012); Bras and Hammond (1996); Amezquita et al. (1995); Yoruk (2004); Subramaniyan et al. (2009).</td>
</tr>
</tbody>
</table>

**Limited research for decision-making between remanufacturing and new acquisition of production equipment**

<table>
<thead>
<tr>
<th>Remanufacturing process and new acquisition process</th>
<th>Subramaniyan et al. (2013).</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bruch (2012); Östlin (2008); Sjödin and Eriksson (2010); Basilekos et al. (2008); Saavedra et al. (2013); Subramaniyan et al. (2013).</td>
<td></td>
</tr>
</tbody>
</table>
technical and economic aspects, however, an economical model will not be proposed in the thesis.

The design of the production equipment to be remanufactured and the remanufacturing process has a high degree of influence as on the possibility to remanufacture the production equipment (Sundin, 2004; Östlin, 2008). Although these factors are important, they are excluded from the scope of the study. This delimitation is partly due to the existence of previous research in this field (Sundin, 2004; Östlin, 2008). Thus, the study is not looking into the implementation after the decision has been made but the decision-making checklist for the decision-making process.

The decision-making checklist is concentrating on two alternatives: remanufacturing the old production equipment or to make a new acquisition of production equipment. To acquire used production equipment is not under the consideration. Because it is usually difficult to purchase used production equipment, which can exactly fit to the specifications and characteristics that manufacturing companies require.

Finally, another important characteristic of production equipment remanufacturing industry is the remanufacturer. However, the thesis excludes the study from the remanufacturer perspective. For the interested reader, the previous study (e.g. Du and Li, 2014, Subramoniam et al., 2013; Du et al., 2012; Sundin, 2004) have investigated remanufacturing from Original Equipment Manufacturers (OEMs) perspective.
2 RESEARCH METHOD

This chapter introduces the approach that is chosen to peruse the research purpose and the specific research questions, discussing methodology theory and the practical data collection.

2.1 Research approach

The purpose of the thesis is to analyze and propose how a decision-making checklist of production equipment remanufacturing versus new acquisition can be carried out so that it contributes to improving production system. The objective can be approached in various ways, and the choice of approach can significantly affect process, results, and validity of the research. A decision-making checklist is a complex process involving changes in all production strategic, technological, economical and organizational dimensions. Thus, the research requires a holistic perspective. According to Williamson (2002), a research is a systematic process of investigation, with clearly constructed parameters and aims at: discovery or creation of new knowledge, testing or confirmation of theory, or investigation of given problem to support decision making process. Every research method has its own characteristic, advantages and disadvantages; the way of collecting, analyzing and presenting the data is also different (Yin, 2003). Before determining which type of research method is carried out in specific situations, each research method should be reviewed and strategies of it analyzed.

Research methods in the social sciences are often divided into two main paradigms: quantitative and qualitative methods. In this thesis, qualitative research is employed in the present research. Qualitative research is characterized by collection and analysis of non-numeric data and usage of a personal interpretive process to gain an understanding of underlying reasons and motivation, and to provide insights into the setting of a problem and generating ideas (Gummesson, 2000). Qualitative research is providing solutions when researchers want to understand the reality, context, and process of certain phenomena that could not be explained properly by quantitative research (Maxwell, 2005).

2.2 Research design of the thesis

The way to design research varies. To choose data collection methods should be based on the selection of research topic, research paradigms, and research questions, etc. (Sundin, 2004). In the previous chapter, the relation between the research purpose and research questions is described. In this chapter, the relation between research questions and research methodology is going to be stated. Leedy (1997) describes that the scientific method is a means by which insight into the unknown is through a cyclic process, and it should be approached in the following steps:

- Clarify the problem that defines the goal of the quest
- Gather the data with the hope of resolving the problem
- Post a hypothesis both as a logical means of locating the data and as an aid in resolving the problem
- Empirically test the hypothesis by processing and interpreting the data to see whether the interpretation of them will resolve the question that initiated the research

The flow of research process of this thesis is following the research cycle that is adapted from Leedy (1997), see Figure 2.
Additionally, the present research is conducted by qualitative method. Therefore, to combine with the cyclical scientific method with mixed-methods design, a detailed and accurate research design for this thesis is adapted according to Maxwell (2005), see Figure 3. There are five components included in the research design: research purpose, conceptual framework, research questions, methods (data collection and analysis methods), and validity (Maxwell, 2005). The methodological discussion is related to, for instance, how to define research purpose and research questions, how to select participating groups or individuals, how to establish relationship with the participants, and how to collect and analyze empirical data. Those recommendations and discussions are taken into consideration under the study.

Five components of the research design are integrated and interacting as a whole. Each component closely connects to several others rather than being linked in a linear sequence. The guideline flow of the research process is showed as Figure 2; however, as Maxwell (2005) further emphasizes that it is inadequate to plan research as a one-dimensional sequence of steps from problem formulation to conclusion. In this research design, to reconsider or modify any component would lead to the new development or changes in some other components.

Figure 2: The cyclical nature of this thesis (adapted from Leedy, 1997).

Figure 3: Qualitative research design of the thesis (adapted from Maxwell, 2005).
The thesis is carried out based on the matrix, see Table 1, which is generated together with the case company at the beginning stages of research. The study consists of three basic steps: first step: “How” describes the theoretical background and illustrates current situation of production equipment in the case company which contains production equipment remanufacturing and new acquisition. Second step “Why” is the analysis of proposed solutions of the research questions as well as identify similarities and discrepancies between the theoretical framework and empirical finding. Based on the results from second step, in order to determine the best solution “What” from investment alternatives of production equipment, suggestions and decision approach are generated and proposed at step three.

Table 1: Research design outline of the thesis

<table>
<thead>
<tr>
<th>Focus points</th>
<th>Context</th>
<th>Chapter</th>
</tr>
</thead>
<tbody>
<tr>
<td>How (current state)</td>
<td>Present the theoretical background</td>
<td>Theoretical Framework Empirics</td>
</tr>
<tr>
<td></td>
<td>Present the empirical data that answers of the research questions are built on</td>
<td></td>
</tr>
</tbody>
</table>
| Why (answer research questions) | • What are the differences between remanufacturing and new acquisition of production equipment?  
• What different levels of remanufacturing of production equipment can be identified?  
• What factors should be considered and analyzed for the decision-making checklist between remanufacturing and new acquisition of production equipment? | Analysis                        |
| What (Decision-making approach) | Draw the conclusion from the results and analysis chapter, propose a decision-making checklist | Conclusions and Recommendations   |

2.3 Research process

The process of the thesis work is from week 4 to week 24, 2014. The author of the thesis is located in the case company from week 4 to week 22. There are five main stages conducted through the whole thesis work. At the first stage of the thesis work, the introduction of the company is conducted in order to have a holistic perspective of the case company: manufacturing process, state of production equipment, maintenance and industrializing and production development is observed, the details of thesis are agreed with the case company including: scope of thesis, time limitation, data collection plan, amount of data needed, confidential information, etc. At stage two, the basic review of literature is carried out. The planning report that consists contact information, preliminary title of the thesis, background of the thesis work, problem description, purpose and research questions, delimitation, frame of reference, research method and time plan is sent to university and company’s supervisor. At the stage three, detailed literature review and data collection is performed. Analysis of the data and data validation is conducted in stage four. At the end of the thesis work, the author of the thesis is focusing on the writing and making modification according to the feedback from the supervisors. At 13th of June 2014, the presentation is held at the university.
2.4 Literature Review

The purpose of a literature review is to establish a theoretical framework of production equipment remanufacturing and new acquisition. It provides preliminary concepts in the research area; it helps to set criteria for selecting candidates for study and to suggest relevant data (Yin, 2003). According to Creswell (2003), four steps in performing literature review is carried out.

- Database: literature review is performed through the use of library resources and Internet database, such as Discovery, DiVA and ScienceDirect. The literature is presented by books, articles and academic journals.
- Identify key words: since the terms “remanufacturing”, “new acquisition” and “production equipment” can be referred to different terms, the key words of the thesis are determined by reviewing more literature. To search the literature, the following key words are combined: production equipment, remanufacturing, new acquisition, machine tool, capital equipment, upgrading, replacement, redesign, renovate, rebuild, purchase, retrofitting, refurbishing and life cycle cost.
- Review literature and select: over 150 articles are screened by reading the abstract part and a quick scan of main body of articles. Around 80 of the most relevant articles are reviewed in detail after the screen process.
- Assemble literature review: after the summaries of literature review, the theories that support the research is adapted and put into the report.

2.5 Data collection

A set of data gathering tools has been conducted for data collection during the thesis work. It is important to collect data using a variety of different methods in order to achieve the best understanding of the complexity and possibility of production equipment remanufacturing and new acquisition. The set of data gathering tools includes: interviews, document studies, observation, brainstorming session, and benchmarking. All those methods have their own strengths and weaknesses. However, to combine all of them can add greater credibility and validity to the quality of the thesis.

2.5.1 Interviews

Interviews are the methodology of choice for much of the data collection activities in the thesis. Interviews are the most commonly used technique for conducting systematic social inquiry (Fontana and Frey, 1994). Interviews are a quick way of getting large amounts of data, gives possibility of immediate follow-up and clarification (Marshall and Rossman, 1999).

In general, three different structures of interviews can be performed: structured, semi-structured, and unstructured. The interview questions for structured interviews are predetermined, and during the interview, the questions are asked in an order. The unstructured interview is an interview in which questions are not prearranged. It allows spontaneity and is not bound to a specific subject. However, semi-structured interviews combine the advantages of both structured and unstructured interviews. The characteristics of semi-structured interviews have both the flexibility and some degree of standard (Bryman and Bell, 2007). In the thesis, the data collected are primarily from open-ended, semi-structured interviews but are supplemented by interview-question guide (see Table 2) and document studies.
Table 2: Interview-question guide

1. What is the definition of production equipment remanufacturing?
2. What is the definition of production equipment new acquisition?
3. What are drivers and challenges for both remanufacturing and new acquisition?
4. What are the differences between production equipment remanufacturing and new acquisition?
5. What degrees of remanufacturing of production equipment can be identified?
6. When does the company decide to upgrade (remanufacture) or replace (new acquire) production equipment?
7. What are the reasons that the case company remanufactures production equipment?
8. Why does the production equipment remanufacturing industry become more and more popular nowadays?
9. Is there any statistics or documentation of production equipment remanufacturing and new acquisition?
10. What factors should be considered and analyzed for decision-model between remanufacturing and new acquisition?
11. What is the production equipment remanufacturing process and acquisition process at the case company? Who is involved in both processes?
12. Who make the decision between those two production equipment investment-alternatives?
13. How long does it take for production equipment acquisition?
14. What are the main differences between production equipment acquisition and other acquisition?
15. Is energy saving as a factor to be considered when conduct production equipment remanufacturing project?

The design of interview-question guide is fundamentally based on the three research questions. Each interview has one respondent, the duration time of one interview is usually one hour. In some cases, one respondent is interviewed two times due to the specific situation. Furthermore, the author of the thesis let the respondents answer freely, yet without changing the subject, in order to get the most information possible out of these qualitative interviews. It is not necessary to ask all of the questions that are listed on the interview-question guide or in any kind of order. The interview-question is modified dependent on the different positions of the respondents and the answers of each question. During the whole thesis work, 14 interviews were conducted, see Table 3.
Table 3: Interview portfolio

<table>
<thead>
<tr>
<th>Position of respondent</th>
<th>Interview date</th>
<th>Time duration</th>
</tr>
</thead>
<tbody>
<tr>
<td>Maintenance engineer</td>
<td>22 Jan 2014</td>
<td>14:00-15:00</td>
</tr>
<tr>
<td></td>
<td>10 Feb 2014</td>
<td>10:30-11:30</td>
</tr>
<tr>
<td>Production engineer</td>
<td>23 Jan 2014</td>
<td>08:30-09:30</td>
</tr>
<tr>
<td>Maintenance engineer</td>
<td>28 Jan 2014</td>
<td>09:00-10:00</td>
</tr>
<tr>
<td></td>
<td>14 Feb 2014</td>
<td>10:00-11:00</td>
</tr>
<tr>
<td>Maintenance manager</td>
<td>3 Feb 2014</td>
<td>10:45-11:30</td>
</tr>
<tr>
<td>Production engineer</td>
<td>7 Feb 2014</td>
<td>10:00-11:20</td>
</tr>
<tr>
<td>Maintenance engineer</td>
<td>17 Feb 2014</td>
<td>09:30-10:00</td>
</tr>
<tr>
<td>Project leader of Industrialization Department</td>
<td>21 Feb 2014</td>
<td>13:30-14:30</td>
</tr>
<tr>
<td>Production engineer</td>
<td>25 Feb 2014</td>
<td>10:00-11:00</td>
</tr>
<tr>
<td>Manager Industrialization &amp; Production Development</td>
<td>25 Feb 2014</td>
<td>15:15-16:15</td>
</tr>
<tr>
<td>Maintenance Technician</td>
<td>6 March 2014</td>
<td>09:00-10:00</td>
</tr>
<tr>
<td>Senior buyer</td>
<td>6 March 2014</td>
<td>13:00-14:00</td>
</tr>
<tr>
<td></td>
<td>5 May 2014</td>
<td>13:00-14:00</td>
</tr>
</tbody>
</table>

2.5.2 Document studies

In order to have an accurate data which increase validity of the thesis, document studies is one of the data collection tools in the thesis. This tool gathers documented data from the case company and completes the data that has been collected through interviews. Through the company’s webpage, qualitative historical data are collected, which is including operation management manual, project model, company’s core values, background, etc.; those data provide a fundamental understanding of the company. Data collection from Maintenance department and Industrialization & Production Development department is also performed in the study.

2.5.3 Observation

Observing the management operations and procedures of the case company provides better information than just relying on the interviews and documents. “Seeing” and “listening” are the keys to observation. Random visits to the factory and participation to meetings and workshops at the case company offers a reliable indicator of what decision-making approach fits the case company the best.

2.5.4 Brainstorming sessions

Two brainstorming sessions are conducted at the case company and the duration of two sessions is around two hours, see Table 4. Six participants with different knowledge and different experiences are invited from Maintenance department, Industrialization & Production Development department and Purchasing department. What establishes the biggest advantage of brainstorming is the high amount of ideas that are generated based on different perspectives. Brainstorming is not only giving a quantitate inputs due to lots of ideas are generated, but also provides qualitative insights which can form part of the chain of problem solving and decision-making.
Table 4: Brainstorming sessions portfolio

<table>
<thead>
<tr>
<th>Brainstorming sessions</th>
<th>Research question</th>
<th>Brainstorming date</th>
<th>Time duration</th>
</tr>
</thead>
<tbody>
<tr>
<td>First brainstorming</td>
<td>RQ1</td>
<td>14 March 2014</td>
<td>13:00-15:00</td>
</tr>
<tr>
<td>Second brainstorming</td>
<td>RQ2 and RQ3</td>
<td>21 March 2014</td>
<td>13:00-15:00</td>
</tr>
</tbody>
</table>

2.5.5 Benchmarking

Three companies are selected for the benchmarking data collection. All of those three companies have very closely business relationships with the case company. The first benchmarking object is one of the subsidiaries under the group that the case company is belonging to. Two of those three companies are the third-party remanufacturing companies, which provide remanufacturing services to the case company. To performing benchmarking, one interview, one on-line interview and one email questionnaire are conducted due to the specific situation, see Table 5. The questions are formulated based on interview-question guide (see Table 2). Benchmarking sets the foundation of performing improvement aimed at enhancing the quality of this thesis. It adds new perspective and provides additional information from the “outsiders”.

Table 5: Benchmarking portfolio

<table>
<thead>
<tr>
<th>Type of Benchmarking company</th>
<th>Conducting method</th>
<th>Benchmarking date</th>
<th>Time duration</th>
</tr>
</thead>
<tbody>
<tr>
<td>Manufacturing company</td>
<td>On-line interview</td>
<td>12 March 2014</td>
<td>10:30-11:30</td>
</tr>
<tr>
<td>The third-party remanufacturing company</td>
<td>Interview</td>
<td>20 March 2014</td>
<td>10:30-11:30</td>
</tr>
<tr>
<td>The third-party remanufacturing company</td>
<td>Email questionnaire</td>
<td>11 April 2014</td>
<td>___</td>
</tr>
</tbody>
</table>

2.6 Analysis of empirical data

According to Eisenhardt (1989), Yin (2003) and Maxwell (2005), analysis of empirical data is one of the most difficult and the least developed aspects of empirical studies. The qualitative analysis is based on the data collected during the interviews and brainstorming sessions at the case company, as well as the benchmarking data. Yin (2003) suggests that data analysis includes examining, categorizing, tabulating and testing. In the study, all collected data are categorized and tabulated, as well as presented in tables and figure, after examining carefully. In addition, most of the data analysis is supported by related literatures.

The study is following Yin (2011) five phases of data analysis: compiling, disassembling, reassembling, interpreting, and concluding. Each phase is briefly explained below.

- Compiling phase: collecting empirical data are organized in a systemic way, for instance, by typing hand-writing records, or the voice records in electronic form with consistent use of words and terms. That makes it very easy to access data during the later phases.
- Disassembling phase: the organized data are broken into small pieces of data. For instance, in the two brainstorming sessions, there are big amount of data collected. A label (post-it note) or a paper clip can be assigned to a group of similar pieces of data. This is a proper approach for collecting multiple factors (Bufardi et al., 2004).
Reassembling phase: the disassembling data can be rearranged and recombined into some meaningful forms. For instance, hierarchical arrays are created for illustrating the different levels of remanufacturing.

Interpreting phase: at this stage, the reassembled data are interpreted. The focus of this phase is to determine the similarities and differences between data and theories.

Concluding phase: the concluding phase could be series of statement that raises the findings of a study to a higher conceptual level and a broad set of ideas (Yin, 2011). At Chapter 5, this thesis is answering the three research questions.

### 2.7 Validity and reliability

Validity and reliability are used to determine research quality. According to Yin (2011), a valid study can be achieved by proper collection and interpretation of data. A common measure to increase the validity of the research is triangulation (Satke, 1994). In the thesis, all of the data are collected from multiple sources. For instance, during the brainstorming sessions and interviews, respondents are from engineering department, maintenance department and purchasing department. Meanwhile, two of benchmarking companies are third-party remanufactures, and the other one is a manufacturing company. In addition, direct observation of the case company and situation of automation, the existing production equipment and the project development process are observed which validate the gathered data. Further, document studies have been done in order to find precise information which might be absent during interviews.

After the study of the analysis, the draft is presented to the respondents. This method is member-checking strategy, which is proposed by Creswell (2003). Member-checking strategies include bringing back to respondents and ask if they agree on the analysis that is based on the empirical data.

Reliability means that two or more researchers studying the same phenomena with similar purpose should reach approximately the same results (Williamson, 2002). Triangulation which is the process of combining multiple sources to clarify meaning, verify the observations or interpretation (Stake, 1994) is used in order to ensure reliability of findings. The triangulation is achieved by conducting structured and unstructured interviews (semi-structured interviews) combined together with the collection of the case company’s internal documents and data sheets.
3 THEORETIC FRAMEWORK

This chapter presents definitions of the terms used in this thesis and also theories that the current research is based upon.

3.1 Production system

Before dealing with research concerning production equipment remanufacturing or new acquisition, it is important to understand the underlying terms of the research. The meaning of terms varies among different authors. The definitions that are adapted in this thesis are outlined below:

The International Academy of Production engineering (CIRP) defines production as “the act of physically making a product from its material constituents, as distinct from designing the product, planning and controlling its production, assuring its quality” (CIRP, 2004).

The definition implies that production just involves the process from raw material to desired products. However, production is often viewed as a complex process involving various elements such as materials, machines, humans, information and methods (Yamamoto, 2013). The term manufacturing is defined as “all functions and activities directly contributing to the making of goods” (CIRP, 2004). Manufacturing includes a broader scope of activities than production, such as introduce a product into market or product development (Chisholm, 1990; Yamamoto, 2013).

The term system refers to a collection of elements which are interrelated in an organized way and work together towards the accomplishment of a certain logical and purposeful end (Wu, 1994). At the same time, a system can itself be divided into subsystems (Groover, 2008). Based on the discussion above, production system can be described as a subsystem of manufacturing system that includes all the elements and activities in order to achieve the goal which is to produce desired products. Hence, in this thesis, production system is defined as:

“The production system is the collection of people, equipment, and procedures that are organized for the combination of materials and processes that comprise a company's manufacturing operations” (Groover, 2008, p.78).

The definition implies that a production system is not an indivisible entity, but is composed by a lot of activities and elements which help transfer a set of inputs into products and services. A production system has to provide sufficient capacity to satisfy the requirements and orders from customers. Further, the production system in the thesis is considered as an open system that affects or is affected by its environment, for instance, the production system has to adapt to the changing context such as customer demands. In addition, a system is a separate unit with system boundaries that can be drawn at different levels or be divided into subsystems (Wu, 1994; Bruch, 2012). Groover (2008) identifies two subsystems of the production system: facilities and manufacturing support system, which is illustrated by Figure 4.

1) Facilities. The facilities of the production system consist of the factory, the equipment in the factory, and the way the equipment is organized.
2) Manufacturing support systems. This is the set of procedures used by the company to manage production and to solve the technical problems and ensuring that products meet
quality standards. Product design and certain business functions are included among the manufacturing support systems.

Those two subsystems of the production system emphasize that a manufacturing company attempts to organize its facilities in the most efficient way to serve the particular mission of that plant. Meanwhile, to operate the production facilities efficiently, a manufacturing company must organize itself to design the processes and plan and control the production process in order to satisfy product quality requirement.

![Figure 4: Description of a production system (adapted from Groover, 2008).](image)

3.1.1 Production equipment

Production equipment is one of the main assets in the facility category of a production system. Manufacturing companies employ all kinds of production equipment that can be used to manufacture a variety of components using a wide range of material types. Fleischer et al. (2006) also claim that the competitiveness of manufacturing companies depends on the availability and productivity of their production facilities. Suzuki (1992) states that improving the production equipment condition is leading to ensure the safety and environment, to increase the quality and delivery performance, to control demand of the production flow as well as to lower the overall cost of the production. Hence, to upgrade or replace production equipment will help the manufacturing companies to achieve their production goals and satisfy customers and eventually increase the revenue. Skinner (1992) argues that making a new investment of production equipment can increase both production performance such as reliability or dependability and financial performance. In addition, Trott and Cordey-Hayes (1996) state that production equipment acquisition provides an opportunity for bringing in new technology into the manufacturing process.

However, in the current economic conditions, the economic efficiency of investment for production equipment must be evaluated in order to permit optimal planning and to meet the budget (Baskakova et al., 2008). Meanwhile, Bruch and Bellgran (2012) state that one of the key issues during production system development is the acquisition of production equipment, which often takes large share of cost in production system development projects. Yamamoto and Bellgran (2009) argue that to sustain the competitiveness at a manufacturing company, copying best practices and buying the latest production equipment may not be sufficient. In addition, Thierry et al. (1995) claim that most purchasing decisions are made with the intention of minimizing the purchasing costs, instead of optimizing life cycle performance, which includes maintenance, reuse, and disposal issues. Hence, new acquisition is not always the best alternative when manufacturing companies aim at upgrading their production equipment. Production equipment remanufacturing are becoming especially important in the current
manufacturing industry, by which the residual value of the used production equipment can be recovered and the production equipment can be remanufactured for the same purpose as during its original life cycle or even for the secondary purpose.

3.1.2 Production equipment Life cycle

Production equipment passes through a series of phases in the course of its life, referred to as the production equipment life cycle. Enparantza et al. (2006) state that the phases that production equipment goes through during its life cycle are the conception, design and development, manufacturing and set-up, operation and maintenance, and disposal stages, shown in the Figure 5.

![Figure 5: Life cycle of production equipment (resource from Enparantza et al., 2006).](image_url)

From the Figure 5, one can see that in general, the average cycle time of production equipment is 12 years. Despite the fact that production equipment has various stages, the operation and maintenance phase is the longest. From the production equipment user’s perspective, life cycle of production equipment is distinguished between three phases in this thesis: acquisition phase, utilization phase and recycling phase (Asiedu and Gu, 1998; Enparantza et al., 2006). Thus, the following three categories from the point of view of the user of production equipment: acquisition cost, operation costs and disposal cost (Enparantza et al., 2006; Asiedu and Gu, 1998; Rose, 2000; Bashkite et al., 2014).

1) Acquisition cost
Acquisition cost is composed of production equipment purchased price plus administration cost, installation costs, transportation costs, etc.

2) Operation cost
Operation cost takes place during the longest period of production equipment life, which is its utilization phase or operation and maintenance phase (see Figure 5). Operation cost includes tooling cost, labor cost, energy consumption, maintenance cost, etc.

3) Disposal cost
Disposal cost takes place during the shortest period, which is at the end-of-stage of production equipment. Disposal cost may include recycling cost and landfill cost. Recycling reclaims material streams useful for application in production equipment. However, landfiling or incineration should be avoided as much as possible on behalf of environment perspective.
3.2 Remanufacturing

To study remanufacturing of production equipment, it is essential to understand remanufacturing under a wide content. The section is reviewing benefits and challenges of remanufacturing.

3.2.1 Product recovery and end of life strategies

Before dealing with research concerning production equipment remanufacturing versus new acquisition, it is essential to understand product recovery options and end of life strategies, since production equipment remanufacturing is one of the alternatives.

Products can be recovered in many ways, and this recovery can be performed at different levels. For instance, at a lower level, it could be the product materials that are recovered. In this situation, it is often called “material recycling”. At a higher level of product recovery, where product, equipment or modules are reused, is often called “remanufacturing”, “reconditioning” or “refurbishment”. Hence, remanufacturing not only promotes the multiple reuses of materials, but it also allows for the steady upgrading of product quality and functionality. It is not necessary to make a new acquisition of a product and scrap used ones (Sundin 2004; Östlin 2008). According to Thierry et al. (1995), an illustration of the linkage between different product recovery options can be seen in Figure 6:

![Figure 6: Product recovery in the closed-loop supply chain (resource from: Thierry et al., 1995).](image)

Returned products, including production equipment can be resold directly, recovered, or disposed. Saavedra et al. (2013) discuss that the recovery options also can be seen as end of life strategies. King et al. (2006) and Rose (2002) define that end of life is the moment in which the products are discarded due to deterioration, technological obsolescence, or change in customer preference. Different product recovery options or end-of-life strategies along with their
definitions and features are addressed in the literature (e.g. Thierry et al., 1995; King et al., 2006; Gray and Charter, 2008). Product recovery options that have been identified are: reuse, repair, refurbishing, remanufacturing, cannibalization, and recycling (Thierry et al., 1995; Saavedra et al., 2013). Table 6 illustrates the definitions and main characteristics of different product recovery options:

Table 6: Product recovery options (based on Saavedra et al., 2013)

<table>
<thead>
<tr>
<th>Product Recovery Options</th>
<th>Definition</th>
<th>Main Characteristics</th>
<th>References</th>
</tr>
</thead>
<tbody>
<tr>
<td>Reuse</td>
<td>The additional use of a component, part or product after it has been removed from a clearly defined service cycle.</td>
<td>Products are used after their first life cycle and do not require any kind of repair or restoration. The potential problems acquired during its first use can be retained. They usually have no warranty of any kind.</td>
<td>Krikke et al. (2004); Gray and Charter (2008); Rose (2000).</td>
</tr>
<tr>
<td>Repair</td>
<td>To return used products to “working order”.</td>
<td>Products only have their damaged components replaced, to maintain product functionality. The warranty is usually only for the components replaced.</td>
<td>Ijomah et al. (2007); Gray and Charter (2008); Ijomah et al. (2004); Thierry et al. (1995).</td>
</tr>
<tr>
<td>Refurbishing/Reconditioning</td>
<td>The process of restoring components to a functional and/or satisfactory state.</td>
<td>Product and its components are returned to use conditions. The warranty for refurbished products is shorter than for a newly manufactured product. It is used for technological upgrades.</td>
<td>Amezquita et al. (1995); Ijomah et al. (2007); Gray and Charter (2008); Ijomah et al. (2004); King et al. (2006); Thierry et al. (1995).</td>
</tr>
<tr>
<td>Remanufacturing</td>
<td>Restore the used products of high value-added into like-new condition.</td>
<td>Recovering the used parts and/or product. They have the same quality and warranty as a new product.</td>
<td>Steinhilper (1998); Gray and Charter (2008); Hauser and Lund (2003); Jacobsson (2000).</td>
</tr>
<tr>
<td>Cannibalization</td>
<td>Recover limited set of reusable parts from used products or components.</td>
<td>In cannibalization, only a small proportion is being reused.</td>
<td>Thierry (1995).</td>
</tr>
<tr>
<td>Recycling</td>
<td>Reuse the material from used products.</td>
<td>The energy built-in, the identity and functionality are lost, as well as the geometry of the original product.</td>
<td>Gray and Charter (2008); Hauser and Lund (2003); Jacobsson (2000); Steinhilper (1998).</td>
</tr>
</tbody>
</table>

According to Table 6, the appropriate product recovery options are dependent on many factors and in many situations. It is essential to understand the differences the product recovery options from remanufacturing (Östlin, 2008). The main difference between reuse and remanufacturing is that the reuse does not require any kind of repair or restoration. Meanwhile, Östlin (2008) states that one similarity with the remanufactured and the reused product is that they are frequently sold in the same marketplaces. Repair involves the fixing and/or replacement of broken parts, but the functional parts are basically not affected (Thierry, 1995). A maintenance staff can handle the repair work. However, in the remanufacturing case, the whole product or production equipment is inspected as a whole. Whether to remanufacture the product or not is determined by if the quality level is reached as customer’s expectation. In this situation, maintenance departments of manufacturing companies do not necessary have the right competence to finish the job instead there is need of a cross-functional group that has detailed knowledge about the production equipment. Thus, the repair process can be considered as a craft and the remanufacturing operation as an industrial process. In addition, remanufacturing might create the possibility to upgrade the product to future standards (Steinhilper, 1998).
By studying the literature, the terms that refer to production equipment remanufacturing and new acquisition are varied. Hart and Cook (1995) propose a practical guide to decision-making between upgrade and replacement. In this model, “upgrade” means production equipment remanufacturing and “replacement” refers to production equipment new acquisition. In addition, Baskakova et al. (2008) and Lad and Kulkarni (2012) define replacement of production equipment as “purchase of new”. Meanwhile, according to literature (Du and Li, 2014; Du et al., 2012; Korugan et al., 2013; Marais, 2013; Moubray, 1997), remanufacturing of production equipment is also referring to production equipment rebuild, perfect repair or extensive repair, and redesign. Galbreth and Blackburn (2006) state that “remanufacturing” refers to restoring a used product to acceptable condition for restoring. Terms “recondition” and “refurbish” are the equivalent terms in literature and practice (Galbreth and Blackburn, 2006). The reviewed literature shows that clear cut on production equipment remanufacturing and new acquisition does not exist in literature nor practice. In this thesis, production equipment remanufacturing includes production equipment retrofitting, refurbishing, recondition and rebuilding. Production equipment acquisition refers to production equipment replacement.

3.2.2 Benefits of remanufacturing

According to previous literature (Du and Li, 2014; Steinhilper, 1998; Thierry et al., 1995; Östlin, 2008; Sundin and Brass, 2005; Gray and Charter, 2008; Hauser and Lund, 2003; Giuntini and Guadette, 2003; Zwolinski et al., 2006; Hatcher et al., 2011), there are four major benefits of remanufacturing: economic, technology, environmental and social. Authors also state that there has been increased interest both in industry and academic filed due to the acknowledgement of benefits of implementing remanufacturing.

- Economic: remanufacturing is usually causing a reduction in used material costs (40-65%), lower the capital investment in plant and equipment acquisition;
- Technology: there is a upgrading of mechanical, electrical systems and control system of automation products. The latest technology can be implemented to guarantee the productivity and effectiveness in the production system;
- Environmental: there is a decrease in the use of resources, reuse of materials, energy consumption, and also reduced pollution and solid waste, including the safe disposal of substances used in the process;
- Social: remanufacturing offers employment opportunities, constant training in different technologies and practices (methods, techniques and tools) used in this process. It could provide the similar quality and warranty as a new product.

3.2.3 Challenges of remanufacturing

As a young business in comparison to manufacturing, the remanufacturing industry faces a lot of challenges as an immature business (Kurilova-Palisaitiene and Sundin, 2013). One of the challenges of remanufacturing is identified by Hammond et al. (1998): the incapability to reach the same level regarding the average quality of OEM(s) and lead time. Sundin (2004) also points out new spare parts must be ordered to the remanufacturing facility, which sometimes can involve long lead times. The scale of these delivery times, combined with product variant proliferation and the inability to predict what types of products will be remanufactured which forces remanufacturers to maintain high inventory levels to avoid bottlenecks in parts supply (Seitz and Peattie, 2004).
Due to the uncertainties of remanufacturing, it is difficult to manage from both remanufacturer and customer’s perspectives. Van Nunen and Zuidwijk (2004) address that the uncertainties of remanufacturing such as processing times, required operations in the remanufacturing process itself as well as uncertainty in quantity, quality, and timing of materials and components that are released from the remanufacturing process.

Mukherjee and Mondal (2009) identify the challenges of remanufacturing are related to the factors, such as managerial factors (product design, acquisition planning, logistics planning, inventory management, marketing, etc.), resource factors (technology and skills of workforce) and environment issues in the disposer market.

3.3 Production equipment acquisition

At this section, the thesis is presenting the concept of production equipment and then identifying the challenges of production equipment acquisition.

3.3.1 Capital equipment

To be able to study production equipment acquisition, the thesis is going to present an overview of the capital equipment to be procured in enterprises. Although the term capital equipment is widely spread in theory and practice, there is no standard definition available (Hofmann et al., 2012; Maucher and Hofmann, 2013). A few relevant definitions are reviewed chronologically:

Swan et al. (2002, p. 795) is cited by Hofmann et al. (2012): “Capital goods are assets used to support business operations. Examples include production lines for manufacturing, testing equipment used by a construction company. Capital goods are typically high-cost, infrequent purchases that require good up-front decision-making to minimize long-term costs.”

Goede (2003, p. 1579) is cited by Hofmann et al. (2012): “Goods with a long useful life (e.g. machinery, factories, raw materials), which are not required in and of themselves but which are necessary for the manufacture of consumer goods and other capital equipment. They are not consumed in one accounting period and generally are depreciated over a number of years (also called: equipment goods, industrial goods, investment goods, producer goods).”

Steiner (2004, p. 337) is cited by Hofmann et al. (2012): “Durable means of production are called capital equipment. During its useful life, it gives off a flow of different usages (e.g. plant equipment). In contrast, non-durable means of production are converted or depleted (e.g. raw materials, auxiliaries, and resources or consumables). For consumer goods as well, the distinction can be made between durable (commodity goods) and nondurable (consumption goods), usually statistically classified according to their life of either more than one year or less than one year.”

Leenders et al. (2006) is cited by Hofmann et al. (2012): “Capital assets are long-term assets that are not bought or sold in the regular course of business, have an ongoing effect on the organization’s operations, have an expected use of more than one year, involve large sums of money, and generally are depreciated. Assets may be tangible or intangible.”
Large (2009, p.12) is cited by Hofmann et al. (2012): Capital equipment presents the tangible assets of fixed assets; thus the tangible items which are to permanently serve the business process.

According to the authors, capital equipment presents tangible and intangible goods that are procured by organizations and that present the technical benefits for the production of goods and services. The characteristic of capital equipment is possible maintenance and repair; also characteristic is the high value of an individual object, for example, production equipment, medical equipment, buildings and software.

Table 7 presents the classification of capital equipment, as well as provides examples (Hofmann et al., 2012), one can see that production equipment is the most common capital equipment, which is the equipment directly used for the production of other goods. In addition, Maucher and Hofmann (2013) state that, capital equipment acquisition plays an important part during the acquisition decisions, especially for production equipment.

Table 7: Classification of capital equipment with examples provided (adapted from Hofmann et al., 2012)

<table>
<thead>
<tr>
<th>Type</th>
<th>Tangible</th>
<th>Intangible</th>
</tr>
</thead>
<tbody>
<tr>
<td>Production related</td>
<td>Simple (individual part)</td>
<td>Electric motor of a CNC machine</td>
</tr>
<tr>
<td></td>
<td>Complex (complete plant or machine)</td>
<td>Production equipment</td>
</tr>
<tr>
<td>Not production related</td>
<td>Simple (individual part)</td>
<td>Truck engine</td>
</tr>
<tr>
<td></td>
<td>Complex (component)</td>
<td>Truck, PC</td>
</tr>
</tbody>
</table>

3.3.2 Challenges of production equipment acquisition

Production equipment acquisition is different from acquisition of other goods and services (Dobler et al., 1990), because it always contains the high financial stakes (Burt et al., 2003; Monczka et al., 2002; Leenders et al., 2009; Talluri, 2002). When talking about equipment acquisition, the cost of the production equipment is essential in determining whether or not a piece of equipment is to be acquired. “Cost”, however, does not just refer to the acquisition cost, but also the operation cost.

Since production equipment has a long useful life (Leenders et al., 2009), operation cost may far exceed the production equipment acquisition price and is thus the most important cost factor (Burt et al., 2003; Perry, 1998; Dobler et al., 1990). According to Leenders et al. (2009), risks associated with production equipment acquisition can be high due to high financial stakes and uncertainty of payment flows. Therefore, production equipment acquisition is a matter of significant strategy in a manufacturing company. In many cases, production equipment’s technological obsolescence is high, which lead to the question of the optimal replacement time or the upgrading levels. Production equipment must be integrated into an existing operation environment, manufacturing companies’ operation plan and interdependences have to be considered when making an acquisition decision (Perry, 1987; Leenders et al., 2009).
Furthermore, production equipment is very sensitive to business cycles (Maucher and Hofmann, 2012), which leads to a high variability of production equipment specification and prices as well as delivery time (Doubler et al., 1990); also the variability of specification is the main reason that manufacturing company could not acquire a precisely used production equipment that can meet the requirement.

One of the characteristic of acquisition process is that production equipment is not acquired frequently (Monczka et al., 2002; Leenders et al., 2009; Burt et al., 2003), therefore, Holmes (1991) point out that buyers are typically less experienced in production equipment acquisition compared with the other materials or spare parts acquisition. The other challenge of production equipment acquisition, described by Maucher and Hofmann (2013), is the manufacturing lead time of production equipment that can be several months or even years, because production equipment often has a low degree of standardization (Burt et al., 2003; Dobler et al., 1990).

Player-related production equipment acquisition characteristics comprise the formulation of a buying center or buying steel committee by members of the acquisition company (Mattson and Salehi-Sangari, 1993). The purchasing department is always playing the role as a facilitator, coordinator and consultant for other departments (Burt et al., 2003; Dobler et al., 1990). In some cases, the purchasing department is even not involved in production equipment acquisition at all (Fearon and Bales, 1995). Woodside and Liuykko (1999) state that due to high financial stakes associated with production equipment acquisition, several authority levels in enterprises are likely to be involved. During the acquisition process, other player-related characteristics, such as internal relations and personal negotiations are also very important (Newman and Simkins, 1998).

### 3.4 Decision-making approaches

At this section, decision-making approaches that are proposed from previous literature are reviewed.

#### 3.4.1 Review of decision-making approaches

From the previous literature, there are a few literatures that are involved in making intelligent choices for production equipment among the available product recovery options, such as major repair, rebuild, recondition or purchase of new production equipment. Baskakova et al. (2008) propose two steps to optimize upgrading the basic production equipment: 1) analysis of the upgrading costs and determination of the standard life; 2) evaluation of the possible replacement of production equipment by calculating both capital and current expresses and their economic efficiency, taking account of the discounting of the capital expenditures and the constrains on the available financial resources and loan sources.

A checklist that is regarding to the decision-making process of upgrading versus replacement of production equipment is suggested by Hart and Cook (1995). The attributes of this checklist involve the various costs of equipment price, down-time expense, operator experience, start-up time, productivity, energy cost and machine age. At the same time, Hart and Cook (1995) point out that when creating a checklist and optimal weight model, it is suggested that these attributes are included. After condensing two alternatives for all attributes, determine which option is weighted more heavily.

#### 3.4.2 PESTEL analysis
The decision on production equipment remanufacturing and new acquisition is influenced by many factors; a holistic approach is needed to address these factors. PESTEL analysis is a comprehensive approach developed by Carpenter and Sanderse (2009) for screening macro factors that affect the working environment of an organization. PESTEL stands for Political, Environment, Societal, Technical, Environment and Legal aspects of organization’s work environment. PESTEL has been successfully used as a comprehensive framework for studying company’s macro environment in different business sectors (Carpenter and Sanderse, 2009). PESTEL analysis contains two phases:

- First phase: with the help of typical lists of PESTEL factors, implementation process starts with determining the relevance of the typical factors to a practical context (e.g. production equipment remanufacturing and new acquisition). Interviews, brainstorming sessions, literature, and benchmarking are used to collect and identify the influencing factors.
- Second phase: relevant factors are grouped and categorized in an informative hierarchy which is meaningful and logical to a particular content. The aim of grouping is to facilitate proper addressing of identified factors; factors belong to a group can be addressed similarly and managed by one authority.
4 EMPIRICAL FINDINGS

This chapter presents empirical findings and qualitative data, which has been collected from the case company and external environment.

4.1 Background of the case company

Volvo Construction Equipment (VCE) is one of the nine Volvo Business Areas of the Volvo Group. It is the world’s largest manufacturer of dumpers and one of the world’s largest manufacturers of wheel loaders, excavation equipment, motor graders and compact construction equipment. Volvo Construction Equipment’s products, spare parts and services are offered worldwide in more than 125 markets. Customers are using the products in a number of different applications including general construction, road construction and maintenance and in the refuse, mining and forestry industries. Manufacturing facilities are located in Sweden, Germany, France, Poland, USA, Mexico, Brazil, South Korea and China.

4.1.1 Volvo Production System

In the manufacturing industry, a recent trend is to apply lean production to achieve greater efficiency and productivity (Liker, 2004). Volvo Production System (VPS) is a philosophy that is inspired from the success of Toyota Production System (TPS). From 2005, Volvo Group initiated “pre-study” to develop VPS strategy that is based on an overview of existing production system. After three years of practice and academic studies, a vision that represent Volvo Group, Volvo Production System was lunched, and it is defined as (Volvo Group, 2014): The structure of VPS is shown as Figure 7.

*Volvo Production System (VPS) is a customer-driven, people-oriented, unifying system that serves as the source of common principles and practices to create customer value and eliminate waste from our processes. VPS is aiming at facilitating operational excellence to meet customer satisfaction as well as achieve continuous improvement.*

![Figure 7: The Volvo Production System pyramid with principles (Source: Volvo Group, 2014).](image-url)
tools and techniques beneficial for implementation of the system. That means the entire decision-making that is conducted through the company has to be based on VPS in order to meet customer satisfaction and to ensure long term commitment to continuous improvement.

4.2 Current state of production equipment at the case company

In this section, it presents the reasons of investment on production equipment at the case company, and the historical data of remanufactured and new acquired production equipment from 2003 to 2013 is presented.

4.2.1 Production equipment investment

The reasons to initiate a production equipment investment are various, for instance, existing tooling or requirement is worn and no longer meets quality requirements; parts and service is no longer available, and it is becoming difficult to maintain; a competitive threat demands equipment modernization. At the case company, making an investment in order to improve or replace existing production equipment is typically triggered by one or more of a variety of factors, see Table 8.

Table 8: Reasons for production equipment investment at the case company

<table>
<thead>
<tr>
<th>Reason</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Replacement, rationalization</td>
<td>The need for investment in a production system can be initiated by the replacement due to efficiency that new or remanufactured production equipment can bring.</td>
</tr>
<tr>
<td>Core values: quality, safety, environment</td>
<td>Requirements for quality, safety, environment, etc. may initiate a need for investment in production equipment that meets these requirements.</td>
</tr>
<tr>
<td>New/ modified products</td>
<td>Products evolve and changes are needed to meet market requirement and existing production equipment is not capable of handling.</td>
</tr>
<tr>
<td>Capacity, insourcing</td>
<td>Investment in new production equipment can be initiated due to that existing equipment cannot handle the needs of capacity (which may have increased due to volume increase, insourcing, etc.)</td>
</tr>
</tbody>
</table>

To combine those reasons together, investing production equipment at the case company is to continuously improve production system and contribute to the overall growth of the case company by adding value to the customers.

4.2.2 Remanufactured production equipment

At the current state, there are 265 pieces of production equipment in the case company’s plant. In this content, production equipment refers to manufacturing equipment; it does not include equipment such as lifting equipment, washing equipment, etc.

According to theoretic framework, the theoretical life cycle time of production equipment is generally from 12 to 15 years old. There are 205 production equipment located at the age range from zero to 14 years, which means 77% of the production equipment is under the theoretical life-cycle-time range. From Figure 8, it is clear that the number of production equipment is the highest at the age range between 6 to 8 years old. The age of 162 production equipment is under 8 years old, which represents 61% of total production equipment. Thus, from the age
range perspective, the case company has a healthy distribution of production equipment. The age of production equipment is one of the significant factors to determine if the specific production equipment needs to be invested (remanufacturing or new acquisition), but it does not necessarily affects the decision-making.

At the case company, 17 pieces of production equipment has been remanufactured between 2003 and 2014. The average age when the production equipment was remanufactured was 20 years old. Table 9 is illustrating the acquisition year and remanufactured year of those 17 production equipment.

**Table 9: Acquisition year and remanufactured year of remanufactured production equipment**

<table>
<thead>
<tr>
<th>Number of production equipment</th>
<th>Acquisition year</th>
<th>Remanufactured year</th>
<th>New counted age</th>
<th>Age when remanufactured</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>1975</td>
<td>2007</td>
<td>7</td>
<td>32</td>
</tr>
<tr>
<td>2</td>
<td>1976</td>
<td>2007</td>
<td>7</td>
<td>31</td>
</tr>
<tr>
<td>3</td>
<td>1984</td>
<td>2007</td>
<td>7</td>
<td>23</td>
</tr>
<tr>
<td>4</td>
<td>1985</td>
<td>2007</td>
<td>7</td>
<td>22</td>
</tr>
<tr>
<td>5</td>
<td>1987</td>
<td>2008</td>
<td>6</td>
<td>21</td>
</tr>
<tr>
<td>6</td>
<td>1987</td>
<td>2003</td>
<td>11</td>
<td>16</td>
</tr>
<tr>
<td>7</td>
<td>1987</td>
<td>2008</td>
<td>6</td>
<td>21</td>
</tr>
<tr>
<td>8</td>
<td>1988</td>
<td>2013</td>
<td>1</td>
<td>25</td>
</tr>
<tr>
<td>9</td>
<td>1988</td>
<td>2006</td>
<td>8</td>
<td>18</td>
</tr>
<tr>
<td>10</td>
<td>1988</td>
<td>2006</td>
<td>8</td>
<td>18</td>
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<td>11</td>
<td>1988</td>
<td>2005</td>
<td>9</td>
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<td>12</td>
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<td>13</td>
<td>1989</td>
<td>2005</td>
<td>9</td>
<td>16</td>
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<td>14</td>
<td>1997</td>
<td>2013</td>
<td>1</td>
<td>16</td>
</tr>
<tr>
<td>15</td>
<td>1998</td>
<td>2014</td>
<td>0</td>
<td>16</td>
</tr>
<tr>
<td>16</td>
<td>1998</td>
<td>2013</td>
<td>1</td>
<td>15</td>
</tr>
<tr>
<td>17</td>
<td>1998</td>
<td>2013</td>
<td>1</td>
<td>15</td>
</tr>
</tbody>
</table>

However, there is no documentation for remanufacturing business cases of those 17 production equipment at the case company, such as production equipment assessment before
decision-making, decision making process before remanufacturing, remanufacturing costs, and follow up checking.

4.2.3 New acquired production equipment

Between 2003 and 2013, 168 pieces of production equipment has been acquired at the case company, see Figure 9. During 2004 and 2006, lean production was introduced to the case company, thus, which was facing a lot of obstacles to apply lean production, and many changes were required. From production equipment perspective, a big amount of existing equipment was worn out and could not meet the increasing manufacturing capacity. In addition, due to the booming industry in the global market during this period, at the beginning of 2007, the case company invested 1.1 billion Swedish kronor to improve production system. 900 million Swedish kronor were invested for machines. Therefore, during 2007 to 2008, activities of production equipment new acquisition were aggressive. 112 pieces of production equipment had been acquired and it took about 67% of total number of acquired production equipment during 10 years.

![Figure 9: New acquired production equipment statistic between 2003 and 2013.](image)

4.3 Production equipment assessment

In the manufacturing company, production equipment is usually used for 12 to 15 years before decision is taken to remanufacture or acquire new one. It is usually a project leader that makes a proposal to decide whether to remanufacture or acquire. Before the decision-making, the manufacturing company must investigate whether the existing production equipment needs to be upgraded and can be remanufactured. Therefore, production equipment assessment and remanufacturability should be performed. At the case company, maintenance engineers are responsible for making the production equipment assessment, which is sometimes presented in an assessment report.

Based on the production equipment assessment examples, six factors are identified for the production equipment assessment:

1) Overall equipment effectiveness
Overall equipment effectiveness (OEE) is the best practices way to monitor and improve the efficiency of the manufacturing processes. OEE is defined as a measure of total equipment performance, that is, the degree to how the production equipment is doing and what it is supposed to do. OEE is simple and practical. It takes the most common and important sources of manufacturing productivity loss, places them into three primary categories and provide an excellent gauge for measuring the condition of the production equipment and how it can be improved.

OEE is a three-metrics analysis tool for equipment performance based on its availability, performance, and quality rate of the output. OEE is calculated as the product of its three contributing factors: OEE = Availability (A) x Performance (P) x Quality (Q).

By integrating the three important metrics commonly associated with manufacturing equipment effectiveness, OEE transforms into a potent tool for performance measurement.

2) Technical upgrading
With the rapid development of manufacturing technology and the demanding requirements of the customers for the efficiency and accuracy of production equipment, a large number of production equipment can go scrapped technically or functionally. Thus, it is essential to identify the condition of production equipment by analyzing mechanical systems, electrical systems and control systems of production equipment.

3) Maintenance costs
Maintenance costs, or the actual current expenditure, that include costs for major repair (in terms of the types of repair) and routine repair (in terms of the types of repair) of each year. The scope of maintenance costs is usually 6 years.

4) Age of production equipment
Age of production equipment is a major consideration in the decision to choose remanufacturing versus new acquisition. At the case company, engineers suggest there is a window of opportunity that moves with time to perform remanufacturing; in some cases, if age of piece of production equipment is outside of the window, then the economically feasible option is to acquire new production equipment. This is because the degradation of mechanical elements (bearings, balancing, gear reducers, etc.) over time, that may limit production equipment’s speed.

5) Mean Time Between Failure and Mean Time To Repair production equipment
Mean Time Between Failure (MTBF) does not apply to an individual component, but is a statistic mean value for the average time between two failures during the normal working life. Mean Time To Repair (MTTR) represents the average time required to repair a failed component or device.

6) Quality
Quality refers to estimate the engineering characteristics of production equipment and the state, quality of manufacture, and operation conditions of the specific production equipment.

Based on the analysis of production equipment from those six factors, an overview of production equipment configuration data has been collected. Engineers are presenting the comments and recommendations that regarding to in which way to and when to remanufacture the production equipment.
Along with the production equipment assessment report, the possible remanufacturing costs will be estimated. Based on the different levels of remanufacturing, different possible remanufacturing costs can be evaluated. At the case company, remanufacturing costs of production equipment usually include the cost of remanufacturing process and overhead cost.

- Cost of remanufacturing process that refers to the total cost of remanufacturing process, including the labor cost during the remanufacturing process, the cost of new purchased parts or subassemblies, the cost of technical upgrading, and cost of material consumption in the remanufacturing process.
- Overhead cost of production equipment remanufacturing refers to an ongoing expense of operating the business of production equipment, including move and installation cost, management fees and utilizes cost.

Production equipment assessment and following with estimated remanufacturing costs provide a clear picture of remanufacturing investment of production equipment when it is decided to be remanufactured by a third party remanufacturer. The manufacturing company has the basic information of their own production equipment and even estimate the remanufacturing costs, which lead the manufacturing company has an efficient and effective communication and negotiation with the third party remanufactures.

4.4 Data collection based on RQs

In the following section the qualitative data that is collected through interviews, brainstorming sessions and benchmarking are presented. It mainly provides the empirical data that the answers of the research questions are built on in the next chapter.

4.4.1 Empirical findings of differences for production equipment remanufacturing versus new acquisition

Before making any decision-making checklist of production equipment remanufacturing versus new acquisition, it is essential to understand the difference between remanufacturing and new acquisition. To compare the differences between those two alternatives is not only establishing the advantages and disadvantages characteristics, but also leading to understand the similarities of them. From the interviews, benchmarking and mainly from brainstorming sessions, there are eight parameters of differences identified:

1) Costs
The decision to remanufacture existing production equipment versus to acquire new one can be a difficult. The main determine parameter is cost according to all the interviews and benchmarking. In general, remanufacturing cost is 30% to 70% of new acquisition cost. However, it is essential to point out that cost for remanufacturing can be higher than acquire new production equipment in some cases. It depends on what level and in which way to implement remanufacturing. However, the detailed costs are not provided, the costs is reviewed as overall costs, which is the cost of whole package of production equipment remanufacturing or new acquisition. That means any related-costs for the two business cases are included. In some cases, to purchase new production equipment can get additional financing for up to 25% of the cost of the purchase to cover installation and training costs.

Managing the operation costs of production equipment through its life-cycle is vital to have profitability. Appropriate remanufacturing or replacing existing production equipment lower part costs and raise the competitive profile. Recently, the case company is running a draft of
Life Cycle Cost (LCC) model and conducting LCC workshops to analyze the machine’s life in terms of its availability (stops disorders and maintenance), cost, and experienced operation and to evaluate alternatives and finally to propose a working method. However, engineers are still testing this LCC model and are constantly making improvements to the model, such as the more cost parameters are included in the analysis in order to achieve a holistic overview. The complete LCC model is going to be a significant tool to analyze the costs of production equipment remanufacturing versus new acquisition.

2) Risks

- Downtime
  To meet the production requirements, it is significant to keep in mind that risks might arise, such as downtime. A lower price of remanufactured production equipment is attractive to the case company, but downtime is not.
  Minimizing manufacturing downtime means preventing machinery malfunctions. Outdated machines slow down the manufacturing process. Manufacturing companies should stay up-to-date on the latest technology, suggest updates to improve productivity and seek opportunities to add capabilities. Downtime minimizing under production equipment remanufacturing and new acquisition is different.

- Uncertainty in the future market
  As products evolve and new technology becomes available, old production equipment gradually becomes increasingly less viable to operation. However, products evolve and changes are needed to meet market requirements, therefore, in which trend of market for specific products is needed to be estimated. Based on the estimation of the trend, the different alternatives of investing production equipment should be adapted. For instance, one specific product is out of production in short period, and then making a decision to acquire new production equipment will be a failure decision.

- Lead time
  Lead Time for production equipment remanufacturing and new acquisition projects are varied from each other. It usually takes 2 to 24 weeks to remanufacture production equipment depending on the desired level that the manufacturing company asks for. In some cases, to require a specific component for the remanufacturing can also take long time. The lead time for production equipment acquisition would take a few months or years due to the high specification (or low standardization) of each individual production equipment.

- Redundancy and buffer capacity
  During a remanufacturing project, the specific production equipment could be off the production line and be remanufactured up to 20 weeks or even more. In some cases, if there is no redundant production equipment, the production line or the specific production cell could be stopped for over 20 weeks, and manufacturing companies need to find ways to meet the running buffer, such as the buffer supply from the partner suppliers or outsourcing. That is also the reason that production equipment remanufacturing is usually carried out in the holiday period. However, to acquire new production equipment could avoid this problem. The installation period of new production equipment is generally taking 2 to 3 weeks, which means the production cell/line can be run over time before the installation in order to meet the buffer capacity in those weeks.

3) Technical performance

New acquired production equipment always provides the latest technology, an improvement program might be initiated because the system is exhibiting high downtime and is identified as
the cause of yield loss. However, by interviewing the senior buyer at the case company, he pointed out that the latest technology would be an obstacle of acquiring new production equipment due to the risk of new technology is high or it might not be mature enough for application. The case company is not willing to be an instigator during the technical exploration; they would rather wait the stable and well tested production equipment. On the other hand, remanufactured production equipment is not necessary applied the newest technology.

4) Safety
When acquiring new production equipment, by affixing the CE marking, the manufacturer is claiming that production equipment complies with the law. In some cases where production equipment has been made to the OEM condition and considered as new production equipment and so subject to CE marking requirements. However, where parts are placed with new similar version do not require re-CE marking.

5) Environment
New production equipment should generate a better working environment, less power and chemicals consumption. Remanufacturing does not necessary conduct total assembly, and it might keep the foundation and bed of the existing production equipment. In addition, the spare parts of old equipment can be sustainably used for the remanufactured production equipment. Remanufacturing is also providing a cost efficient solution on operators training and education. From the reuse of resources point of view, remanufacturing is more advantage than new acquisition.

6) Labor inputs
Different types of labor inputs are required for the alternatives. Remanufacturing needs a broader knowledge and experiences of technicians. Under remanufacturing project, more works need to be conducted in the case company, such as technical decisions and the handling of lager amount of buffer capacity. An investment to acquire new production equipment usually take 140 hours for a project leader, to a production equipment remanufacturing project is generally taking about 300-350 hours. In addition, for acquiring new production equipment, after the contract has been singed, suppliers usually take the most responsibility from the production equipment installation to operators training and following up inspection. After remanufactured production equipment is relocated in the production line, the operators are familiar with mechanical operation, there is just a minor of personal training needed regarding new control system is updated. In contract, for new acquired production equipment, it is not only personal training is significant, but also a new set of education program for the specific production equipment might be required.

7) Lifetime
New acquired production equipment usually has a longer lifetime than a remanufactured one. Remanufacturing is one way to extend the lifetime of the production equipment. However, in some cases, remanufactured production equipment is given a new lifetime, which is equal or even longer lifetime than a new acquired one.

8) Flexibility
Production equipment remanufacturing always grant many levels of remanufacturing scope, for instance, the extended lifetime, the levels of technical upgrading, etc. New acquired production equipment is always given the optimal life-cycle time and newest technology.
4.4.2 Current levels of production equipment remanufacturing at the case company

Understanding the different levels of overall remanufacturing system is a key issue for developing the classifying process as well as benefiting from the results of different levels of remanufacturing in the case company’s day-to-day work; it also helps to achieve a consensus between production equipment remanufacturing and new acquisition. During the data collection at the case company, remanufacturing also refers to total remanufacturing and partly remanufacturing. Total remanufacturing brings production equipment condition to as new-like and partly remanufacturing is less advantage than total remanufacturing. Under those two levels, two sub-categories are identified: technical need and other need. From the technical need perspective, remanufacturing is categorized as mechanical remanufacturing, electrical remanufacturing and control system upgrading. From other needed perspective, remanufacturing can be identified as safety-need remanufacturing, environment remanufacturing and new function-added remanufacturing, see Figure 10. New function-added operation usually cannot be established by partly remanufacturing.

![Figure 10: Breakdown structure of current production equipment remanufacturing.](image)

4.4.3 Factors of decision-making checklist

The empirical data of the factors that can be considered for the decision-making checklist is collected. The description of each factor is briefly explained:

- **Competence**
  Before the decision-making, the case company has to evaluate if there is right skills and competence to carry on both remanufacturing and new acquisitions projects.

- **Automation**
  In which degree of automation is needed for the specific production equipment is also a factor should be considered during decision-making.

- **Adaption into the layout/working places**
  In this point of the view, for example, size of the new invested production equipment, function of the remanufactured equipment should be measured.
• **Capacity**

   It is essential to determine how much sufficient speed is needed to meet the desired capacity. If two existing production equipment need to be updated, instead of acquiring two pieces of new production equipment, the case company usually acquire new production equipment and install it into the production line, meanwhile remanufacture the other one. The advantage of this method is not only achieving capacity requirement but also reduce the buffer capacity during the downtime.

• **Downtime**

   The lead time of remanufacturing and new acquisition projects affect the production equipment downtime. It is significant to plan running buffer for both projects, and then compare which one is more advantage.

• **Environment**

   Environment is including the reuse and recycling of materials and energy efficiency can be achieved for both projects. Further, environment refers to the working environment for the operators, for instance, sound requirement, safety guarantee.

• **Operating costs**

   The costs for personal, maintenance, tools for both remanufacturing and new acquisition projects.

• **Availability of replacement components**

   Remanufacture existing production equipment, one problem would be faced is the spare parts are not available any more or it takes really long time to delivery from the suppliers. There is no such problem when acquiring new production equipment, but the storage of spare parts of old production equipment could be wasted.

• **New technology vs. old technology**

   To make investment of production equipment, one of the major factors is to update the technology. However, new technology is not always the perfect solution for production equipment because new technology might not mature enough; the case company would like to apply the technology that has been properly tested by other manufacturing company.

• **Safety**

   A question will be arisen in term of production equipment remanufacturing is: can remanufacturing achieve adequate machine safety or can it be labeled CE marking.

• **Lifetime**

   Lifetime of production equipment means how long the production equipment needed to continue to serving. If a piece of production equipment is needed just for two more years due to products evolve, to acquire new production equipment is not economical.

### 4.5 Project Model

Due to the production (through replacement, rationalization, quality, safety, environment, etc.), product project (through new/changed products) and operation strategy (capacity, resources etc.), new acquisition of machines and/or production development projects can be initiated. The process of production equipment investment is also guided by the Project Model.

The purpose of Project Model is to ensure the quality of new acquisition production equipment and production development projects, which is including production equipment remanufacturing. Project Model consists of six phases and six gates, see Figure 11. In each phase, main activities are described:

- **Initiation phase:** perform a primary investigation of the potential of an idea. A new project is requested is the input of the whole project model. To describe background and problems, to identify the possible links with other projects, to ensure the project
investment budget and to consider global and/or local impact are the main activities of this phase.

- **Feasibility study phase**: define the project / business applicability and benefits. In this phase, to perform stakeholder analysis and problem analysis is essential to provide solid evidence when comes to decision-making of different potential alternatives. To define goals, time, costs and project origination also needs to be carried on.

- **Concept study phase**: work out the decided solution and prepare for Investment Request. The purpose of this phase is to determine a final investment decision-making checklist of production equipment remanufacturing versus new acquisition, which is also the purpose of the thesis.

- **Planning phase**: finalize a detailed development and prepare for implementation. Project group is focusing on planning industrialization activities and detailed specification, such as buying long lead time production equipment or short lead time production equipment with higher price; how much and in which level production equipment should be remanufactured.

- **Implementation phase**: repair, test and validate the functionalities for full implementation.

- **Trimming-in phase**: perform full implementation and complete the project.

- **Closing phase**: hand over project and finalize White Book.

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**Figure 11: Summary of Project Model with gate-passage and main deliverables.**

At concept study phase, the main output is to determine a best solution between production equipment remanufacturing and new acquisition. The current state of the case company, three factors: cost, profitability, and capacity/consequence, are analyzed for decision-making checklist between remanufacturing and new acquisition.

- **Cost**: estimated acquisition costs versus estimated remanufacturing costs. Maintenance department is responsible for estimating remanufacturing costs after a production equipment assessment is done, see section production equipment assessment. New acquisition cost is estimated by both production development department and purchasing department based on the production equipment market price and old price of same kind of production equipment.
Profitability: is determined by the investment criteria: Internal Rate of Return (IRR), Net Present Value (NPV) and payback period are estimated and analyzed. Net present value is the present value of future cash flows minus the present value of the cost of the investment. IRR is the discounted rate that makes the NPV of an investment zero. NPV, Internal rate of return (IRR) and Net present value (NPV) are two very practical discounted cash flow calculations used for making capital budget decision. NPV and IRR lead to the same decisions with investment are independent. Payback period is the amount of time required for an investment to generate after-tax cash flows sufficient to recover its initial cost.

Capacity/consequence: the purpose to estimate the production capacity is to meet further demands for products.

An example of analysis of decision-making process of production equipment new acquisition and remanufacturing at the case company is shown at Figure 12. One can see that estimated acquisition cost of new production equipment is 7.5 million Swedish kronor is higher than the estimated remanufacturing cost, which is 2 million Swedish krona. The value of IRR and NPV of new acquisition is higher than remanufacturing, as well as payback period of new production equipment is shorter. Redundancy of new production equipment could provide a contingency plan for unscheduled process interruption; however, remanufactured production equipment could not meet this requirement. From the profitability and consequence perspectives, to acquire new production equipment is a wiser decision to make. In fact, the case company made a decision which is to acquire new production equipment. This decision will create necessary capacity and flexibility for volume peaks. In addition, a contingency plan is guaranteed for unscheduled process interruption even through the cost is almost four times of remanufacturing one. The other reason that leads to this decision-making is maintenance cost could be reduced (estimated reduced maintenance cost is 2.5 million Swedish kronor per year) and scheduled preventive maintenance could be improved since maintenance could be done simultaneously with production and not limited to holiday periods.
However, the case company is not satisfied with the current decision-making process. Selection of the most appropriate alternative between remanufacturing and new acquisition should be based on multiple factors. Therefor the purpose of this thesis is to provide a decision-making checklist on selecting the best solution of production equipment investment, while unlike the previous ones in the literature and the current one at the case company, considering holistic approach to develop the proposed model.
This chapter presents the answers of the research problems. The research questions are brought up in each subchapter starting with addressing RQ1 and continuing until RQ3. Further, it identifies the similarities and differences between the theoretical framework and empirical findings. It reflects upon the quality of the thesis.

5.1 Production equipment remanufacturing versus new acquisition

From the previous chapter, the identified differences have been categorized in the results on costs, risks, technical performance, safety, environment, labor inputs, lifetime, and flexibility. In the following section, the answer for RQ1 will be answered and discussed based on the results and the theoretical framework.

RQ1: What are the differences between production equipment remanufacturing and new acquisition?

1) Costs
The main determining parameter of the differences between production equipment remanufacturing and new acquisition is costs (Hart and Cook, 1995; Du and Li, 2014; Korugan et al., 2013). Literature (Thierry et al., 1995; Du and Li, 2014) indicates that the costs of remanufacturing are about 30%-75% of new acquisition costs. From the data collection, costs present the overall costs of the whole package. However, according to literature, the costs could be illustrated into details.

Barnes et al. (1995) state that the costs of remanufactured option include the expense of remanufacturing and the capital costs of later new acquisition as well as the costs of energy losses for both the remanufactured production equipment and its eventual replacement (in some cases). The costs of new acquisition include the capital costs and the cost of energy losses. The comparative evaluation is driven by several factors. Two extremely important factors are the assumption of the remaining life of the remanufactured production equipment and the cost of remanufacturing and reinstallation. The rate of loss valuation is determined through valuing the cost of capacity and production costs (Barnes et al., 1995).

The life-cycle cost comparison is illustrated based on the three identified life-cycle costs categories: acquisition cost, operation cost and disposal cost (Enparantza et al., 2006; Asiedu and Gu, 1998). Acquisition cost of new production equipment is including the project cost and purchasing price. Potter et al. (1997) state that remanufactured equipment offers advantages of lower purchase price and faster return on investment than new production equipment. For remanufactured production equipment, acquisition cost is composed of the project cost and remanufacturing cost. From operation cost and disposal cost perspectives, there is no significant difference between those two alternatives. Operation cost usually refers to maintenance costs, energy consumption, tooling cost, labor cost, etc. (Rose, 2000). Disposal costs consist of recycling costs and landfill costs.

2) Risks
Hart and Cook (1995) state that to compare with downtime expenses of those two alternatives, the production equipment’s repair history should be reviewed. By conducting root cause analysis it is possible to determine if downtime can be minimized by remanufacturing production equipment. If certain component problems cannot be corrected, then new
acquisition of production equipment should be considered. To consider the uncertainty in the future market is also supported by Hart and Cook (1995). Manufacturing companies should base the management decisions on a long-term philosophy, and make an overall growth of companies. Comparing 2 to 24 weeks of remanufacturing period in general, the lead time of new acquired production equipment can be taken up to several months or years (Maucher and Hofmann, 2013; Burt et al., 2003; Dobler et al., 1990). From the financial perspective, Burt et al. (2003) and Monczak et al. (2002) emphasize that compared with lower costs of remanufacturing, new acquisition production equipment have a higher financial stakes, which can lead to higher risk. Production equipment new acquisition is highly dependent on economic trends, leading to a high variability of prices and delivery times for production equipment (Dobler et al., 1990). From the analysis of different factors of risks, one can see that the empirical finding is well supported by the literature.

3) Technical performance
Production equipment to be remanufactured should be enable to integrate new technologies, which includes mechanical, technical and control system remanufacturing. Based on the different levels of remanufacturing, the technical performance can be updated optionally. Hofmann et al. (2012) state that new production equipment provides the technical prerequisites and the most obvious benefit of it is that companies are keeping pace with technological change. New production equipment sharpens the competitive edge and enables to run a more productive line. Technical performance can be a parameter that distinguishes the difference between remanufacturing and new acquisition, but it can also be reviewed as a similarity of those two alternatives. To make an investment on production equipment is to improve the performance and meet the requirement of the production strategy.

4) Environment
Production equipment remanufacturing reduces consumption and waste while it reuses a lot of the used parts, such as bed, the large column, the small column, the table and other mechanical parts of high value-added can be recycled(Gray and Charter, 2008; Du and Li, 2014; Zhan et al., 2006). Meanwhile, replacing existing production equipment to new acquired one is also environmental friendly due to less energy consumption. Through a case study, Du and Li (2014) state that through production equipment remanufacturing the energy is saved by over 80% compared with new production equipment manufacturing.

5) Life-cycle time
New life-cycle is given for new acquired or remanufactured production equipment (Kuester et al., 2011; Du and Li, 2014) or a service-life is extended due to the lower level of remanufacturing (Thireey et al., 1995). Remanufactured production equipment has become the more advanced form of the original, existing production equipment or new acquired production equipment, with the characteristics of multiple life cycle developments (Du and Li, 2014).

6) Flexibility
Different levels of production equipment remanufacturing can be conducted. However, the inherent reliability of any new production equipment is established by its design and by how it is made of OEMs (Moubray, 1997).

Based on the empirical findings and combined with the analysis, the main differences between production equipment remanufacturing and new acquisition is summarized in Table 10.
Table 10: Main differences between production equipment remanufacturing and new acquisition

<table>
<thead>
<tr>
<th>parameters</th>
<th>Production equipment remanufacturing</th>
<th>Production equipment new acquisition</th>
<th>References</th>
</tr>
</thead>
<tbody>
<tr>
<td>Costs</td>
<td>Usually 30-75% cheaper; expense of remanufacture and the capital costs of later new acquisition as well as the costs of energy losses</td>
<td>The capital costs and the cost of energy losses</td>
<td>Hart and Cook (1995); Du and Li (2014); Korugan et al. (2013); Thierry et al. (1995)</td>
</tr>
<tr>
<td>Risks</td>
<td>Higher risk of downtime; higher flexibility to adapt the uncertainty of regarding products lifetime; often short lead time higher risk regarding redundancy and buffer capacity</td>
<td>Lower risk of downtime; manufacturing lead time can be long; lower request of redundancy during the production and less amount of buffer capacity is required; high variability of prices and delivery times; higher financial stakes</td>
<td>Hart and Cook (1995); Maucher and Hofmann (2013); Burt et al. (2003); Dobler et al. (1990); Monczak et al. (2002)</td>
</tr>
<tr>
<td>Technical performance</td>
<td>Not necessary applied the newest technology</td>
<td>Often latest technology</td>
<td>Hofmann et al. (2012)</td>
</tr>
<tr>
<td>Safety</td>
<td>Lower safety guarantee, unit remanufacture might not provide re-CE marking</td>
<td>Higher safety guarantee</td>
<td>Empirical support</td>
</tr>
<tr>
<td>Environment</td>
<td>Reduce consumption and waste generation while reusing lots of the used parts</td>
<td>Generate a better working environment, less power and chemicals consumption</td>
<td>Gray and Charter (2008); Du and Li (2014); Zhan et al. (2006)</td>
</tr>
<tr>
<td>Labor inputs</td>
<td>More labor inputs; Minor personal training</td>
<td>Less work content; personal training and proper education is required</td>
<td>Empirical support</td>
</tr>
<tr>
<td>Life-cycle time</td>
<td>Multiply life-cycle development; new life-cycle time is given or service-life is extended</td>
<td>A new life-cycle time</td>
<td>Kuester et al. (2011); Du and Li (2014); Thierry et al. (1995)</td>
</tr>
<tr>
<td>Flexibility</td>
<td>Different levels of remanufacturing</td>
<td>Lower flexibility due to the inherent reliability is established by its design</td>
<td>Moubray (1997)</td>
</tr>
</tbody>
</table>

From Table 10, one can see that there are no related references to support the two parameters of differences between production equipment remanufacturing and new acquisition: safety and labor inputs. Whether to remanufacture or to acquire new, it is crucial that production equipment or technology meet safety standards, and that companies must conduct due diligence. The extent of the improvement made to the existing production equipment, together with its provenance, can result in new legal obligations on the owner (or user) undertaking such work. In some cases where production equipment has been so transformed or substantially remanufactured it can be considered as new production equipment and so subject to the conformity assessment and CE marking requirements. However, lower levels of remanufacturing, where parts are replaced with new similar versions might not require re-CE marking. In comparison with new acquired production equipment, CE marking is required for all new manufactured production equipment. Therefore, from one of the interviews that have been conducted in the case company, one of the engineers answers that: “new production equipment is generally safer than remanufactured one, even though the safety can be built in remanufactured production equipment.”
Labor inputs are identified as one of the parameters of differences between remanufacturing and new acquisition due to different levels of work content, personal training and education are needed. Based on the project leader’s experience, a remanufacturing project usually involves a higher degree of work content, where project leaders tend to spend more working time on the remanufacturing project. Compare with the new acquired production equipment, operators on the work floors are familiar with the technical operation of remanufactured production equipment, less training and education is needed.

5.2 Levels of production equipment remanufacturing

To make an investment of production equipment, besides acquiring the latest and greatest machinery, there are many options to consider for production equipment remanufacturing. Remanufactured production equipment, for instance, can improve cycle times and qualities, while production equipment upgrades can add productivity-monitoring features that are common on new production equipment (Suzuki, 1992; Skinner, 1992; Trott and Cordey-Hayes, 1996). Therefore, one problem has been raised, in which level production equipment should be remanufactured. The answer to this question is dependent on the electrical and/or mechanical status of production equipment and availability of spare parts, and combined with how much the manufacturing company is willing to invest (Baskakova et al., 2008; Aronson, 2003).

In the case company, the terms total remanufacturing and partly remanufacturing are referred to in the daily work, in some cases, they are all treated as remanufacturing. Consequently, manufacturing companies are unable to communicate efficiently internally and with remanufactures that remanufacture production equipment for the users, due to different terms involved. A clear definition of different levels of remanufacturing can help manufacturing companies to create and ensure that it reach the exact level and specification of production equipment that are desired. Three different levels of remanufacturing are identified through empirical study and inspired by literature (Thierry et al., 1995; Ijomah et al., 2007; Gray and Charter, 2008; Ijomah et al., 2004; Amezquita et al., 1995; King et al., 2006; Ijomah, 2002; Jacobsson, 2000).

RQ2: What different levels of remanufacturing of production equipment can be identified?

- Total remanufacturing

Among all the available options of production equipment remanufacturing, total remanufacturing involves the greatest level of work content and as a result its products have superior reliability and quality and the processing time of total remanufacturing is the longest. In total remanufacturing, production equipment that is known to be worn, or discarded are brought to a manufacturing environment, where all but the machinery bed and frame are completely disassembled and remanufactured. All components are cleaned and inspected. Those that can be reused are brought up to specification. Those that cannot be reused are replaced. When the production equipment is reassembled and examined, it is ready for a second life at the manufacturing company, and perform as new. Existing production equipment can often be upgraded to like-new quality and technology for 50-60% of the cost of new production equipment (Thierry et al., 1995; Du and Li, 2014). Thus, potential benefits of total remanufacturing are: a reduction in material costs for the production equipment’s main body; a reduction in energy costs and a reduction in overall environment impact, and the most important benefit is, a reduction of financial costs (King et al., 2006; Ijomah et al., 2004).
Before starting the total remanufacturing process, used production equipment is usually at end-of-life stage. Total remanufacturing is particularly applicable when combining technical remanufacturing, such as, mechanical remanufacturing, electrical remanufacturing and control system upgrading with other kinds of remanufacturing, such as safety remanufacturing or environment remanufacturing. Meanwhile, Steinhilper (1998) argue that remanufacturing also creates the possibly to upgrade the product to future standards, which refers to new function-added remanufacturing. From the life cycle perspective, total remanufacturing is giving production equipment a new life cycle time, the length of new given life cycle is equal to first life cycle, or beyond (Du and Li, 2014; Steinhilper, 1998; Jacobsson, 2000; Gray and Charter, 2008).

Since the quality of the totaly remanufactured production equipment is “like-new”, the equipment is treated in the same way as new equipment: similar quality and speed (performance), same products are produced (Ijomah, 2002; Ijomah et al., 2004), which means the same guarantee function or insurance is provided to remanufactured production equipment as equivalent new one. Further, the new function or fixtures could be added (new function-added remanufacturing) in order to achieve the higher specification and meet customer’s requirement, with the result that total remanufactured production equipment could produce new products.

Based on the description above and literature studies (Ijomah et al., 2004; Thierry et al., 1995; Steinhilper, 1998; Gray and Charter, 2008; Hauser and Lund, 2003; Jacobsson; 2000), the definition of total remanufacturing is proposed: it is the only process where existing production equipment are brought at least to original equipment manufacturer (OEM) performance specification from the owner’s perspective, and at the same time, are given the guarantee function that are equal to those of equivalent new production equipment.

- Partly remanufacturing

In the production equipment remanufacturing industry, in some case, production equipment does not require to be “like-new” condition in order to adapt the company’s manufacturing strategy. For instance, a company is planning to introduce new products in four years; however, the production equipment needs to be upgraded. In this case, it is the waste of money and energy to conduct a total remanufacturing project, instead, the production equipment just need to be remanufactured to a satisfaction working period instead of a new life cycle time that equals the newly manufactured production equipment. According to the company’s manufacturing strategy and operations, such as customer expectation, financial support, decision making process, and relationship with partners and suppliers can also affect the manufacturing company to conduct partly remanufacturing projects on production equipment.

Production equipment that is going to be partly remanufactured is usually very close or at the end-of-life stage. Partly remanufacturing involves less work content than total remanufacturing (Ijomah et al., 2004). This is because partly remanufacturing usually requires the rebuilding of major components to a working condition that is generally inferior to that original production equipment. Consequently, quality standards are less rigorous than new production equipment. In partly remanufacturing process, production equipment is partly disassembled, all major components that have failed or that are on the point of failure will be replaced or rebuilt, even where the manufacturing company has not reported or noticed faults in those components. Compared with total remanufacturing, partly remanufacturing is not always offering the latest technology or functionality. Technology upgrading is either mechanical remanufacturing or
electrical remanufacturing or partly mechanical remanufacturing combined with partly electrical remanufacturing or control system upgrading.

In many cases, it is optimal to just make a partly mechanical remanufacturing or control system upgrading. The purpose of partly remanufacturing is to bring the existing production equipment up to a specified and desired condition. Partly remanufacturing significantly improves production equipment’s quality and extends its life cycle time. However, remaining service-life of the equipment is generally less than the life cycle time of a new one. Thus, the guaranteed function for partly remanufactured production equipment is lower than a newly manufactured one. This visual image makes it clear that the partly remanufactured production equipment is not returned to its original condition but has been improved to desired condition. Even though compared with total remanufacturing, the quality and the guarantee function of production equipment are generally lower, but there are potential benefits that come along with partly remanufacturing: 1) it is easier to plan production equipment’s downtime; 2) there are less economic risks; and 3) operation time for partly remanufacturing is shorter.

The definition of production equipment partly remanufacturing is: the process that returns existing production equipment into a required working condition that is inferior to the original specification, at the same time, partly remanufactured production equipment contains a guaranteed function that is lower than that of a newly manufactured equivalent (Thierry et al., 1995; Amezquita et al., 1995; Ijomah et al., 2004; Gray and Charter, 2008; King et al., 2006).

In some cases, the case company needs to extend the capacity of specific production equipment. The strategy is carried on as to acquire a new set of production equipment, and put it into the production line, while the existing production equipment is being partly remanufactured. After partly remanufacturing has been finished, there are two sets of production equipment available with the desired condition which the case company demands. The advantages of applying this strategy are: 1) there is no stop time of production of the specific production equipment, which also avoids building the product-buffer, 2) expend the production capacity in a gradual manner and 3) it is a priori strategy for strategic products related production equipment or/and production equipment which has extremely capital intense.

- Unit remanufacturing
  In the first two levels of remanufacturing, production equipment is a complete or a big proportion of disassembling. In unit remanufacturing, only a specific part of production equipment is being remanufactured. Existing production equipment usually is not so close to the end-of-life stage when it is being remanufactured at this level.

In this stage, a unit or a few units of production equipment is examined and replaced. From the whole concept of production equipment point of view, total or partly disassembly is not conducted. Instead, a significant unit of production equipment that has failed or is on the point of failure is rebuilt or replaced, such as a motor, spindle or a worktable. Unit remanufacturing comes out of an identified risk and is normally limited to a specified part of the production equipment, it could be mechanical, electrical or control system. However there are a few benefits of unit remanufacturing: 1) it takes the shortest time to bring production equipment to working condition, 2) it is a cost effective alternative and 3) it is the most flexible alternative, but the work content is more than that of repairing.
The difference between production equipment unit remanufacturing and repair is that repairing just involves the fixing and/or replacement of broken parts (Thierry et al., 1995). It is simply the correction of specified faults (Ijomah et al., 2004). However, components remanufacturing is not fixing the broken parts, but it rebuilds and/or replaces the whole unit that the parts belong to. For instance, one bearing in a drilling unit is broken, to replace it with a new bearing is repairing; however, unit remanufacturing is replacing or rebuild the whole unit based on the awareness of other bearings could have the same problem as the broken one in the near future.

Therefore, the definition of unit remanufacturing is proposed: it is simply replaced and/or rebuilt a unit and brings existing production equipment to a better working condition that is much inferior to the original (total remanufactured) and partly remanufactured specification. It has the lowest guarantee function among all the levels of remanufacturing. Table 11 is summarizing the definitions of different levels of remanufacturing.

Table 11: Proposed definitions of different remanufacturing levels

<table>
<thead>
<tr>
<th>Remanufacturing</th>
<th>Definition</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total remanufacturing</td>
<td>It is the only process where existing production equipment are brought at least to original equipment manufacturer (OEM) performance specification from the owner’s perspective, and at the same time, are given the guarantee function that are equal to those of equivalent new production equipment.</td>
</tr>
<tr>
<td>Partly remanufacturing</td>
<td>The process that returns existing production equipment into a required working condition that is inferior to the original specification, at the same time, partly remanufactured production equipment contains a guarantee function that is lower than that of a newly manufactured equivalent</td>
</tr>
<tr>
<td>Unit remanufacturing</td>
<td>It is simply replaced and/or rebuilt a unit and brings existing production equipment to a better working condition that is much inferior to the original (total remanufactured) and partly remanufactured specification. It has the lowest guarantee function among all the levels of remanufacturing.</td>
</tr>
</tbody>
</table>

5.2.1 Differentiation of defined levels of production equipment remanufacturing

By grouping and categorizing the description of three levels of remanufacturing, seven indicators are identified: the scope of required work content, the performance that should be obtained, the value of guarantee function that can be guaranteed, the life-cycle-time that is implied, the end-of-life stage that belongs, disassembly level that are required and technical support that are involved, see Table 12. The main characteristics of indicator are described, as well as corresponding references are provided in terms of each indictor.
Table 12: Seven indicators of each production equipment remanufacturing level

<table>
<thead>
<tr>
<th>Indicator</th>
<th>Total remanufacturing</th>
<th>Partly remanufacturing</th>
<th>Unit remanufacturing</th>
<th>References</th>
</tr>
</thead>
<tbody>
<tr>
<td>Work content</td>
<td>Greatest degree of work content because of the total disassembling</td>
<td>Less work content of total remanufacturing. All major components will be rebuilt or replaced</td>
<td>Lowest degree of work content as specified unit need be rebuilt or replaced.</td>
<td>Ijomah et al. (2004); Ijomah (2002); Östlin (2008).</td>
</tr>
<tr>
<td>Performance</td>
<td>At least to OEM original performance specification from production equipment’s perspective</td>
<td>The specification is inferior to that of original production equipment</td>
<td>Inferior to those of total remanufactured and partly remanufactured</td>
<td>Thierry et al. (1995); King et al. (2006).</td>
</tr>
<tr>
<td>Guarantee function</td>
<td>At least equal to that newly manufactured equivalent</td>
<td>Less than those of newly manufactured equivalent</td>
<td>The lowest value of guarantee function</td>
<td></td>
</tr>
<tr>
<td>Life-cycle-time</td>
<td>A second life-cycle-time is given, at least equals to that of new one</td>
<td>Extend the life-cycle-time to desired requirement</td>
<td>Extend the life-cycle-time, but shorter than partly remanufactured</td>
<td>Asiedu and Gu (1998); Enparantza et al. (2006).</td>
</tr>
<tr>
<td>End-of-life</td>
<td>At the end-of-life stage</td>
<td>Very closer or at the end-of-life stage</td>
<td>Not quite close to the end-of-life stage</td>
<td>Empirical finding support</td>
</tr>
<tr>
<td>Disassembly level</td>
<td>Total disassembly</td>
<td>Major partial disassembly</td>
<td>A specific portion of partial disassembly</td>
<td>Thierry et al. (1995); Saavedra et al. (2013).</td>
</tr>
<tr>
<td>Technical support</td>
<td>Mechanical remanufacturing and electrical remanufacturing and control system upgrading</td>
<td>Either mechanical remanufacturing or electrical remanufacturing or control system upgrading</td>
<td>Limited technical support for specific situation</td>
<td>Empirical finding support</td>
</tr>
</tbody>
</table>

Table 6 at Chapter Theoretical Framework is compared with analysis of different levels of remanufacturing, one can see that products remanufacturing is similar to the proposed production equipment total remanufacturing in the this thesis, characteristics of products refurbishing or reconditioning are similar to production equipment partly remanufacturing.

The case company is a Swedish company, 80% of the data collection is through Swedish. The term “remanufacturing” is translated from “renovering” in Swedish. The respondents are referring “renovering” as retrofitting, recondition, rebuilding, refurnishing, etc, but mostly as remanufacturing. It is difficult to distinguish those terms in the daily work. The respondents prefer to use terms: total remanufacturing and partly remanufacturing, which can obviously and literally represent the different levels of remanufacturing, and it is easy to understand, instead of using confusing terms (e.g. retrofitting, recondition, rebuilding, refurnishing). Östlin (2008) and Sundin (2004) also state that those terms are often used synonymously. In addition, those two articles (Östlin, 2008; Sundin, 2004) are both conducted in Sweden. Marsek (2003) states that there are no measurable standards for remanufacturing, rebuilding, retrofitting and recondition, which leads gross mismanagement underestimation of the complexity of
remanufacturing projects. Marsek (2003) argues that researchers should propose different levels of remanufacturing.

Ijomah et al. (2007) define three operations: remanufacturing, reconditioning, and repair, during the development of design for products remanufacturing. These three operations are ranked based on the work content, warranty and quality (performance), see Figure 13.

Based on this hierarchy of remanufacturing development, the thesis is considering from a holistic view by identifying multiple indicators to differ the levels of production remanufacturing, see Figure 14. The hierarchy of remanufacturing is a net-shaped structure. Every indicator effects the categorization of levels of remanufacturing. Shafiee et al. (2009) state that different warranties are offered by dealer or third party, who also sets the sales price. That means “warranty” is usually involved in selling or reselling process. However, to remanufacture production equipment by the third-party remanufacturer and then return the remanufactured production equipment to the user/owner is not involving with “selling or reselling”. In addition, the respondents of the thesis believe that “guarantee function” is the accurate term as a guide to production equipment’s quality. Figure 14 is illustrating how seven indicators affecting the different levels of production equipment remanufacturing.

Figure 13: Remanufacturing development in a hierarchy (source: Ijomah et al., 2007).
5.2.2 Connection and definition of production equipment remanufacturing

Previous literature (Haynesworth and Lyons, 1987; Ijomad et al., 2004; Seaver, 1994; Lund, 1996) refers “remanufacturing” as “products remanufacturing”, such as a compute, phone, or engine, those products involves less investment for the owner compare with production equipment. Remanufactured products are always resold to customers; however, remanufactured production equipment is not resold, but is returned back to the owner. In addition the definition of remanufacturing from literature (Haynesworth and Lyons, 1987; Ijomad et al., 2004; Seaver, 1994; Lund, 1996) is rather focusing on the products remanufacturing process, e.g. inspection, disassembly, part replacement/refurbishment, cleaning, reassembly, and testing to ensure it meets the desired product standards. However, in those definitions, “desired standards” are not specified. Definition of production equipment remanufacturing is limited from literatures.

Amezquita et al. (1995) describe remanufacturing as “the process of bringing a product to like-new condition through reusing, reconditioning, and replacing component parts.” Through this definition, the final aim of remanufacturing is bring products to like-new conduction; meanwhile, remanufacturing is including reconditioning and replacing components parts. Therefore, definitions of remanufacturing from previous literature are insufficient. The data collections undertaken during this thesis also indicate that production equipment remanufacturing should be defined as different levels. From user/owner of production equipment point of view, reselling is not involved instead return of remanufactured production equipment.

Du and Li (2014) define that remanufacturing is a series of steps acting on the end-of-life stage in order to turn products to like-new or better performance, including the process of redesign, part conditioning, upgrading and reassembly. Through the analysis of the thesis, to
remanufacture production equipment is not always acting on the end-of-life stage; part recondition could not sufficiently return production equipment to like-new condition. The definition is ambiguous.

New definition of production equipment remanufacturing is proposed:

Production equipment remanufacturing is aiming at bringing production equipment to like-new condition through total remanufacturing, partly remanufacturing and unit remanufacturing. Three levels of production equipment remanufacturing are categorized based on seven indicators: work content, performance, guarantee function, life-cycle-time, end-of-life, disassembly level and technical support.

5.3 Factors are considered and analyzed for decision-making checklist

RQ3: What factors should be considered and analyzed for the decision-making checklist between remanufacturing and new acquisition of production equipment?

1) Investment costs
The investment cost is a critical factor in making production equipment remanufacturing versus new acquisition decision. The cost to remanufacture is usually less expensive than the cost to acquire new production equipment. Upgrading is often a less costly way to incorporate new technologies into an existing system (Hart and Cook, 1995). However, remanufactured production equipment is not exactly like-new; therefore it does not always give new equipment advantages. It is important to review designed objectives to determine in which level of remanufacturing should be conducted (keopfer, 1993).

2) Profitability
Manufacturing strategies are formulated in accordance with cooperate objectives, and to be profitable is the most important objective for most manufacturing companies. Profitability comparison for remanufacturing versus new acquisition is determined by Internal Rate of Return (IRR), Net Present Value (NPV) and payback period (see section 4.5).

3) Labor costs
As Hart and Cook (1995) state that it is a mistake that some decision-makers fell that operators are flexible enough to flow with any changes that are made. Many operators are effective using current production equipment. Therefore, it is much easier to be sensitive to the ingrained expertise of operators. Meanwhile, the education and training cost is relatively cheaper.

4) Further industry growth
If an industry has a health growth rate, future sales potential should be considered in the decision-making process. To make a partly remanufacturing is a typical example to meet the desired criteria of a short-term growth.

5) Capacity/speed
When making production equipment remanufacturing versus new acquisition decision, it is imperative to consider long-term capacity goals. Hart and Cook (1995) state that with a goal to increase line speed by 15%, remanufacturing may be the best choice; however, with long-term goal to increase output by 50%, to acquire new production equipment may be the best alternative. In some cases, manufacturing companies do not just need a complete remanufacturing, but also require enhancing production equipment with added spindles, and overall high speed.
6) Maintainability
Certain production equipment idiosyncrasies with the current production equipment will remain consistent when using remanufacturing approach. Hart and Cook (1995) state that when installing new production equipment, preventive maintenance procedures often must be relearned. On a complex level, engineers often must develop an understanding of new technology.

7) Ergonomics/working environment
In terms of production equipment, ergonomics is about designing for people (operators). The emphasis within ergonomics is to ensure that designs complement the strengths and abilities of people and minimize the effects of their limitations, rather than forcing them to adapt. Qualified ergonomists are optimizing performance, safety and comfort, thus, good designed ergonomics provide a better working environment for the operators.

8) Competence/organization
It is important to have the available and right resources and skills or competence to carry out remanufacturing project.

9) Reuse/recycling
Older base casting offers an advantage in the remanufacturing process. In some cases, older “settled iron” is more rigid. However, sometimes the older foundation of production equipment cannot accept newer technology (Aronson, 2003).

10) Spare parts
Availability of spare parts is another concern when considering remanufacturing versus new acquisition. With older production equipment, parts sometimes become more difficult to obtain, which create longer downtime due to parts sourcing (Sundin, 2004; Baskakova et al., 2008; Aronson, 2003). Hart and Cook (1995) suggest that one way to combat this problem is to inventory unusual or obsolete parts: however, this can become difficult and expensive. On the other hand, to acquire new production equipment makes it easier to source needed, directly from suppliers and in a reasonable delivery time.

11) Production equipment age and lifetime for serving
Age of production equipment is a major consideration in the decision process. As Aronson (2003) and Hart and Cook (1995) state most companies make an investment of production equipment, and there is a window of opportunity that moves with time to perform investment. Usually the age of a piece of production equipment is outside of the window, then the economically feasible to remanufacture or new acquire a new piece of production equipment. The reason is that when production equipment reaches a certain age, the degradation of mechanical elements and electrical system may limit speed, as well as control system is out-of-date. Continue serving lifetime depends on the production strategy or new products evolve, that is also one of the reasons to lead to identify the different levels of remanufacturing.
6 CONCLUSION AND DISCUSSION

The final chapter of the thesis is to focus on presenting the final conclusion and discussion the results and also to outline the scientific and industrial contribution as well as to suggest direction for future research.

6.1 Implementation approach

The implementation approach presented in this chapter has been developed through Chapter 4 Empirical findings and Chapter 5 Analysis, as well as the theory presented in Chapter 3. Through the study of previous literature, terms such as model, method, and guideline have been mixed. Therefore, it is necessary to clarify the developed implementation approach. Table 13 is presenting the key terms’ descriptions, which are not supposed to be seen as general definitions, but a description of how terms have been treated in this thesis.

Table 13: Descriptions of the key terms in the developed implementation approach (adapted from Bengtsson, 2007, that cited from Nationalencyklopedin www.ne.se)

<table>
<thead>
<tr>
<th>Term</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Method</td>
<td>A systemic procedure in order to achieve a specific result</td>
</tr>
<tr>
<td>Guideline</td>
<td>An instruction of the main features of a certain activity and how it will be carried on</td>
</tr>
<tr>
<td>Model</td>
<td>A presentation of a phenomenon</td>
</tr>
<tr>
<td>Checklist</td>
<td>A list of activities and/or factors to take into consideration</td>
</tr>
<tr>
<td>Factor</td>
<td>A circumstance that influences a certain result</td>
</tr>
</tbody>
</table>

6.2 Decision-making checklist

Production equipment remanufacturing versus new acquisition decisions is often uncounted in the manufacturing environment. A systemic approach can be used to aid in the decision-making process. Many variables or factors should be analyzed in order to reach a wise decision. The framework for decision-making includes first identifying relevant factors and determining influencing factors that directly relate to the context of production equipment remanufacturing and new acquisition by using two phases of PESTEL analysis, which was reviewed at Chapter 3: Secondly, list all the identified influencing factors into a checklist, and compare each influencing factor between production equipment and new acquisition and make a final decision.

Table 14 demonstrates the implementation of first phase of PESTEL analysis. At this phase, high and medium relevant PESTEL factors are used to identify context related factors which affect the decision on selecting the best alternative between production equipment remanufacturing and new acquisition.
Table 14: Typical PESTEL factors affecting production equipment remanufacturing and new acquisition, Rel. = Relevance, based on Carpenter and Sanderse, 2009

<table>
<thead>
<tr>
<th>1 Political factors</th>
<th>Rel.</th>
<th>2 Economic factors</th>
<th>Rel.</th>
<th>3 Social factors</th>
<th>Rel.</th>
<th>4 Technological factors</th>
<th>Rel.</th>
<th>5 Environment factors</th>
<th>Rel.</th>
<th>6 Legal factors</th>
<th>Rel.</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.1 Economy infrastructure quality</td>
<td>High</td>
<td>2.1 General growth trends</td>
<td>High</td>
<td>3.1 Attitude towards consumerism</td>
<td>High</td>
<td>4.1 Hardware</td>
<td>High</td>
<td>5.1 Pollution and deforestation</td>
<td>High</td>
<td>6.1 Health and safety legislation</td>
<td>Med.</td>
</tr>
<tr>
<td>1.2 Regional and global law</td>
<td>Med.</td>
<td>2.2 Interest rate</td>
<td>Med.</td>
<td>3.2 Entrepreneurial spirit</td>
<td>High</td>
<td>4.2 Software</td>
<td>High</td>
<td>5.2 Sustainability</td>
<td>High</td>
<td>6.2 Regulation on waste and energy</td>
<td>High</td>
</tr>
<tr>
<td>2.3 Funding sources</td>
<td>Med.</td>
<td>3.2 attitude towards environmentalism</td>
<td>Med.</td>
<td>4.3 Equipment</td>
<td>High</td>
<td>5.3 Recycling</td>
<td>High</td>
<td>6.3 Environmental protection laws</td>
<td>High.</td>
<td></td>
<td></td>
</tr>
<tr>
<td>2.4 Inflation and exchange rates</td>
<td>Med.</td>
<td>3.4 Willingness of individuals to work</td>
<td>Med.</td>
<td>4.4 Material</td>
<td>High</td>
<td>5.4 Waste disposal</td>
<td>Med.</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>2.5 Economic competitiveness</td>
<td>High</td>
<td></td>
<td></td>
<td>4.5 New technologies</td>
<td>High</td>
<td>5.5 Energy-efficiency</td>
<td>High</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>2.6 Globalization Vs. Localization</td>
<td>Med.</td>
<td></td>
<td></td>
<td>4.6 New products</td>
<td>High</td>
<td>5.6 Move towards more environmentally friendly products</td>
<td>Med.</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>2.7 Labor cost</td>
<td>High</td>
<td></td>
<td></td>
<td>4.7 New processes</td>
<td>High</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>4.8 Skills availability</td>
<td>High</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>4.9 IT for management and communication</td>
<td>High</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Med.</td>
</tr>
</tbody>
</table>
Table 15 shows the results of identification and grouping of influencing factors which is directly related to the context of production equipment remanufacturing and new acquisition, which is the second phase of PESTEL analysis. At this phase, the identification process start by interviews, brainstorming sessions, benchmarking and gathering any factor that could be related to the problem. Further, factors collected from three research questions, from both Empirical findings and Analysis parts. The initial list of these factors is distilled to a shorter list which has factors that are matched with factors identified in the first phase of PESTEL analysis.

Table 15: Influencing factors of production equipment remanufacturing versus new acquisition

<table>
<thead>
<tr>
<th>Hierarchy 1</th>
<th>Hierarchy 2</th>
<th>Influencing factors</th>
<th>PESTEL ref.</th>
<th>References</th>
</tr>
</thead>
<tbody>
<tr>
<td>Business factor</td>
<td>Economical factors</td>
<td>Investment costs</td>
<td>2.1, 2.2, 2.3, 2.5</td>
<td>Hart and Cook (1995); Du and Li (2014); Korugan et al. (2013)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Profitability</td>
<td>2.1, 2.5</td>
<td>Section 4.5 Project model</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Operation costs</td>
<td>1.1, 4.1, 4.2, 4.6</td>
<td>Enparanza et al. (2006); Asiedu and Gu (2010)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Labor costs</td>
<td>2.7</td>
<td>Hart and Cook (1995)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Training/education costs</td>
<td>4.6, 4.9</td>
<td>Empirical support</td>
</tr>
<tr>
<td>Market factor</td>
<td>Future industry growth</td>
<td>Age and serving lifetime</td>
<td>2.1, 2.5, 2.6</td>
<td>Cook and Hart (1995)</td>
</tr>
<tr>
<td>Engineering factors</td>
<td>Production equipment factors</td>
<td>Standard and interchangeable item</td>
<td>4.5, 4.8, 4.9, 5.3</td>
<td>Toffel (2003); Seitz and Wells (2006)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Production equipment architecture</td>
<td>4.1, 4.2</td>
<td>Zwolinski et al. (2005); Rose (2002)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Adaption into production/layout/cell</td>
<td>4.5, 4.7, 4.8, 4.10</td>
<td>Empirical support</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Capacity/speed</td>
<td>3.1, 3.2</td>
<td>Hart and Cook (2005)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Spare parts availability</td>
<td>4.1, 4.4, 4.9</td>
<td>Sundin (2004); Baskakova et al. (2008); Aronson (2003)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>products evolve</td>
<td>4.7</td>
<td>Empirical support</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Maintainability</td>
<td>3.4, 4.3</td>
<td>Empirical support</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Ergonomic</td>
<td>3.4, 4.3</td>
<td>Empirical support</td>
</tr>
<tr>
<td>Technology performance</td>
<td>Mechanical upgrading</td>
<td>4.1, 4.5</td>
<td>Hofmann et al. (2012)</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Electrical upgrading</td>
<td>4.1, 4.5</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Control system</td>
<td>4.2, 4.5</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Process factors</td>
<td>Competence/organization</td>
<td>3.2</td>
<td>Empirical support</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Lead time</td>
<td>4.3, 4.4, 4.9</td>
<td>Maucher and Hofmann (2013); Burt et al. (2003); Dobler et al. (1990)</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Redundancy and buffer capacity</td>
<td>4.3, 4.9</td>
<td>Empirical support</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Downtime</td>
<td>4.1, 4.2, 4.3</td>
<td>Hart and Cook (1995)</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Safety</td>
<td>4.5</td>
<td>Empirical support</td>
<td></td>
</tr>
<tr>
<td>Environmental factors</td>
<td>Sustainability</td>
<td>5.2, 5.3</td>
<td>Gray and Charter (2008); Du and Li (2014); Zhan et al. (2006)</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Energy-efficiency</td>
<td>5.5</td>
<td>Du and Li (2004)</td>
<td></td>
</tr>
<tr>
<td>Societal factors</td>
<td>Working environment</td>
<td>3.4</td>
<td>Empirical support</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Attitude towards consumerism</td>
<td>3.1</td>
<td>Carpenter and Sanderse (2009)</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Entrepreneurial spirit</td>
<td>3.2</td>
<td>Carpenter and Sanderse (2009)</td>
<td></td>
</tr>
</tbody>
</table>
The final factors are shown in Table 15 and grouped into four major categories: business factors including economical factors, in addition to political and legal factors that affect the business aspect of the problem; engineering factors includes technical factors related to production equipment remanufacturing and new acquisition processes; environmental factors include factors related to resources utilization and factors related to energy-efficiency that could be caused by both remanufacturing and new production equipment; societal factors include factors that affect people who are targeted and factors that affect the entire society. Political and legal factors can be allocated to the category addressed by these factors. For example political and legal factors that address the environmental aspect of the problems are grouped with factors under the same category. In Total, there are 28 influencing factors are identified.

After two phases of PESTEL analysis, all the influencing factors are collected. Therefore, the final decision-making checklist of this thesis is proposed, see Table 16.

Table 16: The decision-making checklist

<table>
<thead>
<tr>
<th>Hierarchy 1</th>
<th>Hierarchy 2</th>
<th>Influencing factors</th>
</tr>
</thead>
<tbody>
<tr>
<td>Business factors</td>
<td>Economical factors</td>
<td>Investment costs</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Profitability</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Operation costs</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Labor costs</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Training/education costs</td>
</tr>
<tr>
<td>Market factor</td>
<td></td>
<td>Future industry growth</td>
</tr>
<tr>
<td>Engineering factors</td>
<td>Production equipment factors</td>
<td>Age and serving lifetime</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Standard and interchangeable item</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Production equipment architecture</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Adaption into production/layout/cell</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Capacity/speed</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Spare parts availability</td>
</tr>
<tr>
<td></td>
<td></td>
<td>products evolve</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Maintainability</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Ergonomic</td>
</tr>
<tr>
<td>Technology performance</td>
<td></td>
<td>Mechanical upgrading</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Electrical upgrading</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Control system</td>
</tr>
<tr>
<td>Process factors</td>
<td></td>
<td>Competence/organization</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Lead time</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Redundancy and buffer capacity</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Downtime</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Safety</td>
</tr>
<tr>
<td>Environmental factors</td>
<td></td>
<td>Sustainability</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Energy-efficiency</td>
</tr>
<tr>
<td>Societal factors</td>
<td></td>
<td>Working environment</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Attitude towards consumerism</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Entrepreneurial spirit</td>
</tr>
</tbody>
</table>

6.2.1 An example of implementation of the decision-making checklist

A decision-making checklist is a complex process involving changes in all production strategic, technological, economical, environmental and societal dimensions. Table 17 is illustrating an example of the decision-making checklist for a specific piece of production equipment. “X” indicates that production equipment remanufacturing or new acquisition has more advantages over the other one.
Table 17: An example of implementation of the decision-making checklist

<table>
<thead>
<tr>
<th>Influencing factors</th>
<th>Re.</th>
<th>New acquisition</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Remanufacturing</td>
<td>New acquisition</td>
</tr>
<tr>
<td>Investment costs</td>
<td>X</td>
<td>4.2 MSEK</td>
<td>6.0 MSEK</td>
</tr>
<tr>
<td>Profitability</td>
<td>X</td>
<td>IRR 26%; NPV 6 MSEK; payback period 8.5 years</td>
<td>IRR 47%; NPV 7.4 MSEK; payback period 4 years</td>
</tr>
<tr>
<td>Operation costs</td>
<td>X</td>
<td>3.6 MSEK</td>
<td>1.1 MSEK</td>
</tr>
<tr>
<td>Labor costs</td>
<td>X</td>
<td>21 MSEK</td>
<td>5 MSEK</td>
</tr>
<tr>
<td>Training/education costs</td>
<td>X</td>
<td>0.2 MSEK</td>
<td>0.7 MSEK</td>
</tr>
<tr>
<td>Future industry growth</td>
<td>X</td>
<td>The future sales potential might decrease</td>
<td></td>
</tr>
<tr>
<td>Age and serving lifetime</td>
<td>X</td>
<td>Production equipment is 21 years old</td>
<td>12 years serving lifetime after partly remanufacturing</td>
</tr>
<tr>
<td>Standard and interchangeable item</td>
<td>X</td>
<td>The third party remanufacturer is fully responsible for all interchangeable items.</td>
<td></td>
</tr>
<tr>
<td>Production equipment architecture</td>
<td>X</td>
<td>The size of new production equipment is smaller</td>
<td></td>
</tr>
<tr>
<td>Adaptation into production/layout/cell</td>
<td>X</td>
<td>New production equipment has higher degree of automation and smaller size fits the cell better</td>
<td></td>
</tr>
<tr>
<td>Capacity/speed</td>
<td>X</td>
<td>The goal is to increase line speed by 15%, remanufacturing is a better alternative</td>
<td></td>
</tr>
<tr>
<td>Spare parts availability</td>
<td>X</td>
<td>Spare parts are rarely available due to this type of production equipment is not produced anymore</td>
<td></td>
</tr>
<tr>
<td>Products evolve</td>
<td>X</td>
<td>Light weighting products to reduce manufacturing costs and environmental impact</td>
<td></td>
</tr>
<tr>
<td>Maintainability</td>
<td>X</td>
<td>Maintenance staff has a better knowledge of current equipment</td>
<td></td>
</tr>
<tr>
<td>Ergonomic</td>
<td>X</td>
<td>New production equipment is easier to operate</td>
<td></td>
</tr>
<tr>
<td>Mechanical upgrading</td>
<td>X</td>
<td>There is no need of fully disassembly of mechanical system, partly remanufacturing is enough reach the goal</td>
<td></td>
</tr>
<tr>
<td>Electrical upgrading</td>
<td>X</td>
<td>Need a fully upgrading of electrical system</td>
<td></td>
</tr>
<tr>
<td>Control system</td>
<td>X</td>
<td>Need a fully upgrading of control system</td>
<td></td>
</tr>
<tr>
<td>Competence/organization</td>
<td>X</td>
<td>Available and right resources and skills to carry on remanufacturing project</td>
<td></td>
</tr>
<tr>
<td>Lead time</td>
<td>X</td>
<td>12 weeks</td>
<td>1.5 years</td>
</tr>
<tr>
<td>Redundancy and buffer capacity</td>
<td>X</td>
<td>Need 12 weeks of buffer capacity</td>
<td>Need of 3 weeks of buffer capacity during the new equipment installation</td>
</tr>
<tr>
<td>Downtime</td>
<td>X</td>
<td>New production equipment is minimizing downtime the most</td>
<td></td>
</tr>
<tr>
<td>Safety</td>
<td>X</td>
<td>Partly remanufacturing achieve adequate the safety</td>
<td></td>
</tr>
<tr>
<td>Sustainability</td>
<td>X</td>
<td>Reuse of production equipment foundation and some materials</td>
<td></td>
</tr>
<tr>
<td>Energy-efficiency</td>
<td>X</td>
<td>Much Less fuel and electric consumption of new production equipment</td>
<td></td>
</tr>
<tr>
<td>Working environment</td>
<td>X</td>
<td>New production equipment has great advantage of sound control</td>
<td></td>
</tr>
<tr>
<td>Attitude towards consumerism</td>
<td>X</td>
<td>Remanufacturing is becoming a trend</td>
<td></td>
</tr>
<tr>
<td>Entrepreneurial spirit</td>
<td>X</td>
<td>Due to the environmental friendly and cost-efficiency, the manufacturing company encourages remanufacturing projects</td>
<td></td>
</tr>
<tr>
<td>Total number of factors</td>
<td>13</td>
<td>15</td>
<td></td>
</tr>
</tbody>
</table>

From this example, one can see that, there are 13 factors that support production equipment remanufacturing and 15 factors support production equipment new acquisition. The decision-making checklist is providing a systemic analysis of each influencing factor regarding to two alternatives; however, it is not a systemic approach to determine which alternative is the best.
according to the number of factors. As the author of the thesis pointed out previously that the decision-making checklist is an aid approach of decision-making process of production equipment remanufacturing versus new acquisition.

6.2.2 Discussion of the decision-making checklist

This thesis proposes a decision-making checklist in decisions between remanufacturing and new acquisition of production equipment. The decision-making checklist is based on data collection through the case company and benchmarking companies, as well as literature. Three research questions are providing the inputs to the final decision-making checklist.

From the theoretical framework study, a cost based decision-making approach is proposed by Baskakova et al. (2008). This decision approach is completely dependent on cost/benefit data which varies by time; this makes the practical use of the method questionable due to the significant efforts needed to keep real time data. Through the approach focus on an important aspect of production equipment remanufacturing versus new acquisition: economical feasibility, yet it lacks the ability to consider other aspects which depend on unquantifiable factors.

Many mathematical models exist for decision-making process. However, the thesis suggests a systematic and holistic approach for evaluating the two general production equipment alternatives of remanufacturing versus new acquisition. When using mathematical models, it is difficult to factor in subjective parameters needed for reliable decision-making (Hart and Cook, 1995). Further, the variables needed for solving mathematical models are often unavailable and unrealistic. Further, Azhar and Leung (1993) state that mathematical models in technology selections have been criticized for being impractical, failing to capture long-term strategic issues, and being unable to deal with factors such as quality and flexibility.

Hart and Cook (1995) propose a checklist to identify several of factors to determine which alternative is weighted more heavily. The advantages of this checklist are taking consideration of quantitative and qualitative data at the same time, inclusion of decision maker preferences. However, the checklist that Hart and Cook (1995) proposed could contain more factors from a holistic perspective. The checklist should include factors from technology performance and environment influence aspects. Therefore, the checklist proposed by Hart and Cook (1995) is lack of analysis by a holistic approach. Therefore, the decision-making checklist of this thesis is based on PESTEL analysis to collect general factors in a systemic and holistic perspective.

The other disadvantage of the checklist that Hart and Cook (1995) is proposed that after considering two alternatives for all decision factors, determine which option is weighted more heavily by accounting how many factors that support each alternative. Firstly, this weighting method is not supported by any theoretical framework; secondly, for each decision-making case of production equipment remanufacturing versus new acquisition contains different scenario for the manufacturing company. In some cases, company consider the investment as the preliminary factor; on the other hand, technology performance upgrading could be the priority instead economical factors.

The decision-making checklist of this thesis is built on PESTEL analysis. PESTEL suits the nature of decision-making between different alternatives in the sense of inclusiveness and comprehensiveness (Ziout et al., 2014). In addition, a reliable and realistic decision-making checklist should be based on a holistic approach that considers all aspects of production
equipment remanufacturing and new acquisition. Further, the decision-making checklist is following the guideline of the current decision-making checklist (section 4.5) at the case company, the advantages is that engineers are familiar with the procedures but combine with more influencing factors in order to achieve a holistic approach.

Depending on the different situation, it is not necessary to determine all the influencing factors at every decision-making. Manufacturing companies can decide which influencing factors should be included or excluded for each case. Meanwhile, in some scenarios, it is essential to include other considerations, for instance, companies could choose remanufacturing because remanufacturing investment funding can be taken out of maintenance budget; production equipment new acquisition investment funding would be categorized under investing costs. In order to adapt the investment policy of the company, a different decision could be made.

6.3 General discussion

The previous chapters can be briefly summarized as follows. The research in this thesis started by recognizing the importance of improvements of production system and investment of production equipment, which establish sustained competitive advantages in production. In Chapter 1, the problem of production equipment investment is that there is limited research for decision-making of remanufacturing versus new acquisition for user. Thus, the purpose of the thesis was proposed. The methods employed in those studies are explained in Chapter 2. Chapter 3 reviews production equipment remanufacturing can be determined as one of product recovery options. Both production equipment remanufacturing and new acquisition are serving one purpose is that to continuously improve production system, and results in cost-efficient solution and benefits to the overall growth of companies. Chapter 3 also concluded the benefits and challenges of production equipment remanufacturing and new acquisition, which provide a fundamental theoretical support to the RQ1 and RQ3. Having the research purpose as general direction, as well as guided by three research questions, each of which had a rather different topic of study. The empirical evidence collected from the studies is presented in Chapter 4. The evidence is analyzed as well as the answering of three research questions are presented in Chapter 5.

6.3.1 Revisiting the research questions and discussion contribution of the thesis

RQ1: What are the differences between production equipment remanufacturing and new acquisition?
The research question was formulated in order to investigate the difference between production equipment remanufacturing and new acquisition. Eight parameters to distinguish the differences were identified: costs, risks, technical performance, safety, environment, labor inputs, life-cycle time and flexibility, see Table 10.

RQ2: What different levels of remanufacturing of production equipment can be identified?
The research question was formulated in order to investigate the different levels of remanufacturing can be identified. Through seven indicators of each remanufacturing levels (see Table 12): work content, performance, guarantee function, life-cycle-time, end-of-life-time, disassembly level and technical support. Three different levels of remanufacturing are proposed: total remanufacturing, partly remanufacturing and unit remanufacturing. Finally, a new definition of production equipment remanufacturing is proposed. This has added both scientific contribution and industrial contribution to the field and to the case company. Through the data collection at the case company, there was no consensus of different levels of
remanufacturing, which lead to the misunderstanding among engineers. Proposed different levels of remanufacturing can help engineers be able to communicate efficiently internal and with remanufacturers.

**RQ3: What factors should be considered and analyzed for the decision-making checklist between remanufacturing and new acquisition of production equipment?**

The research question was formulated in order to provide the influencing factors to the decision-making checklist. Through this research question, 11 relevant factors were collected through interview, benchmarking and brainstorming sessions. By combining RQ1, RQ3 and PESTEL analysis, a systemic and holistic decision-making checklist is proposed at Chapter 6.

### 6.4 Conclusion and future research

Make a decision between production equipment remanufacturing and new acquisition is a complicated one. It involves considerations of many factors that come from different fields. The problem is that the number of factors is large, as well as the interaction between these factors. The study object of the thesis is not a specific kind of production equipment; instead it is in a general level of production equipment. The complicated nature of the problem makes enumeration approaches is failing.

This study successfully develops and implements a holistic checklist for decision-making process of production equipment remanufacturing versus new acquisition. The development of the decision-making checklist benefits from reviewing previous methods and builds on its strength and avoiding its weaknesses. To use PESTEL approach helps identifying the most influencing factors among large number of them. The decision-making checklist not only adds new knowledge to the current research field, but also provides a practical guideline for the case company to implementing. To make the best decision is not only helping company to identify the best scenario of production equipment investment, but also improve the efficiency of production system, which can achieve the best profitability solution and contribute to the overall growth of company.

Firstly, the future study will be applying this decision-making checklist to real cases at the manufacturing companies. Secondly, the possible future study can be conducted is that the ranking all the influencing factors of the decision-making checklist based on the theoretical framework. Meanwhile the ranking of influencing factors should be adapted and based on the real cases of each individual decision-making of production equipment remanufacturing versus new acquisition.
REFERENCES


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