Economic Potential for Remanufacturing of Robotic Lawn Mowers with an Existent Forward Supply Chain

– A case study on Husqvarna

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Upphovsrätt

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Abstract

This project investigates how remanufacturing of robotic lawn mowers can be incorporated into an existent forward supply chain. The project is conducted as a single case study on Husqvarna where an interview study and a literature study provide the empirical data and theory, respectively. Alternatives are proposed for potential remanufacturing cases at various locations, where different parties ranging from original equipment manufacturers to independent manufacturers perform the remanufacturing process. SWOT analyses are conducted to identify the most promising alternatives for a further economic analysis. The economic evaluation is based on net present values and a sensitivity analysis which together determines the feasibility of the alternatives.

The results of the project answer three research questions. The first concludes that out of seven defined production systems there are only two that are not suitable for remanufacturing in a general case mainly due to the low flexibility of these systems. The results of the second identifies labor, logistics, and operational prerequisite factors that must be considered when implementing remanufacturing for case specific alternatives. The conclusion of the third research question lists the feasibility of the alternatives from which the recommendations for Husqvarna are presented.

This project recommends Husqvarna to implement a remanufacturing process for their robotic lawn mowers either by enlisting their current dealers or by themselves at a location nearby the spare parts warehouse in Torsvik. Which alternative is the most profitable depends mainly on the expected quantity of the acquired cores, i.e. Husqvarna as a centralized remanufacturer benefits more from higher quantities while the decentralized dealer alternative would comparably be more profitable if the quantities were lower. As it is perceived that initial collected quantities will be low, and possibly even somewhat higher for the dealers, a decentralized remanufacturing process could be the most profitable alternative to start with. Using a third-party remanufacturer is also feasible but considered risky and therefore not recommended as they could have the same core acquisition problem as Husqvarna while having lower profitability.

Keywords: remanufacturing; economic evaluation; production system; facility location; closed-loop supply chain
Acknowledgments
This work would not have been possible if not for the help and encouragement of many individuals to whom we would like to express our gratitude. We would like to thank:

Our supervisors, Erik Sundin and Louise Lindkvist, for their support and interest in the project, and for all the time spent reading our drafts.

Examiner Ou Tang for providing insightful and astute comments from the view of operations management.

Our contact Jonas Willaredt at Husqvarna, and all other interviewees that took the time out of their busy schedules to answer all our questions.

Our opponents, Jayasheel Ramesh and Vésteinn Sigurjónsson, for their sharp eyes and sharper feedback.

We would also like to thank for the financial support provided by the VINNOVA Challenge-driven innovation initiative and the project ElevatoRe: Elevate remanufacturing to EEE manufacturers’ strategy towards circular economy (Dnr: 2018-00330).
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List of Terms and Abbreviations

Circular Economy - A regenerative system which keeps products and materials in extended use and reduces waste by design (Ellen MacArthur Foundation, 2017b).

CF - Continuous Flow

Closed-Loop Supply Chain - “… focus on taking back products from customers and recovering added value by reusing the entire product, and/or some of its modules, components, and parts.” (Guide Jr & Van Wassenhove, 2009)

Core - Used, worn-out, or discarded product utilized in remanufacturing

Economies of Scale - Reduced costs per unit due to increased total production

EPL - Equipment-Paced Line

FMS - Flexible Manufacturing System

Forward Supply Chain - A supply chain where “…the flow of material is unidirectional, from suppliers to manufacturers to distributors to retailers, and to consumers.” (Souza, 2013)

IR - Independent Remanufacturer

JIT - Just-In-Time

Location in the Supply Chain - (see Supply Chain and section 1.5 for locations of interest)

NPV - Net Present Value
OEM - Original Equipment Manufacturer

OPL - Operator-Paced Line

Production System - A production system is an interconnected network of value-adding processes which transforms inputs (raw materials) into an output (a product) (Bellgran & Säfsten, 2010).

PSS - Product-Service Systems, “… a mix of tangible products and intangible services designed and combined so that they jointly are capable of fulfilling final customer needs” (Tukker & Tischner, 2006).

Remanufacturing - Remanufacturing is defined as a restoration process of a core (used product) through an industrial process up to a condition equal to or better than the original product (Lund, 1984).

Remanufacturing Process - (see Remanufacturing)

Remanufacturing System - “… the system for collecting used/discarded products, remanufacturing of the product, and the delivery of the remanufactured product to the customer” (Östlin, 2006).

Supply Chain - “… the infrastructure of factories, warehouses, ports, information systems, highways, railways, terminals, and modes of transportation connecting consumers and suppliers.” (Frazelle, 2017).

SWOT - Strengths, Weaknesses, Opportunities and Threats
1. Introduction

This chapter aims to help the reader understand the report in full by presenting background information about why the project was conducted. The theoretical and company background in collaboration with the problem description will make the purpose and the presented research questions easier to grasp.

1.1. Theoretical Background

Circular economy is a way to present a sustainable system where resource inputs, wastes and emissions are minimized. This is achieved by creating loops in the supply chain (see Figure 1), where the resources are used multiple times before final disposal. It is possible to use principles such as remanufacturing, long-lasting design, reuse, maintenance, repair, refurbishing and recycling in a circular economy (Geissdoerfer, et al., 2017). Remanufacturing is defined as a restoration process of a core (used product) through an industrial process up to a condition equal to or better than the original product (Lund, 1984). By modernizing or upgrading a remanufactured core it could exceed the specifications of the original product (Sundin & Bras, 2005). The core is disassembled, and the components are refurbished or replaced if needed to meet the quality and performance standard of the new product (Lund, 1984).

![Figure 1 - Circle economy diagram for a user. Modified from Ellen MacArthur Foundation (2017a).](image)

When manufacturing products the choice of an appropriate production system is integral for achieving the desired outputs, in terms of the product and its qualities. A production system is an interconnected network of value-adding processes which transforms inputs (raw materials) into an output (a product) (Bellgran & Säfsten, 2010). These processes are e.g. separating, forming, and assembly (Mattsson & Jonsson, 2003). In his framework, Miltenburg (2005) presents seven types of production systems together with their functions and general layout, each of the systems if chosen having different effects on the outputs that will be provided. These seven types include production systems for all scales of production, from a flexible cellular layout for batch production depending heavily on human resources, to a rigid autonomous continuous flow developed for and specialized in producing a single product.
1.2. Company Background

Husqvarna was founded 1689 as a weapon factory for rifles but has over the years transitioned into producing articles like sewing machines, kitchen equipment, bicycles, motorcycles, chainsaws and power cutters. Some of these articles are no longer being produced by Husqvarna, in part due to changes in the market. Husqvarna are now one of the leading manufacturers of lawn mowers, which they started to produce 1918. A few years later, in 1947, Husqvarna’s first lawn mower powered by an engine was introduced to the market, and in year 1995 Husqvarna’s first robotic lawn mower was produced. (Husqvarna Group, 2019)

Today Husqvarna group is a global company with four divisions; Husqvarna, Gardena, Consumer brands and Construction. Year 2017 the Husqvarna group had a net sale of 39 394 MSEK with over 13 000 employees worldwide, where Husqvarna division had a share of 50 percent of the group’s net sales (the other divisions had 14, 23 and 13 percent share respectively). The last few years Husqvarna have had a positive growth on the market with increasing net sale and net income, which they aim to increase further. Husqvarna Group have an ambition to achieve market leadership by 2020, by outpacing the market growth. (Husqvarna Group, 2018a)

Currently, Husqvarna Group is at the leading edge of the global market of outdoor power products such as chainsaws, trimmers, robotic lawn mowers and ride-on mowers (Husqvarna Group, 2018b). These products are sold to professional business customers, wider consumer segments and to a lesser extent through online channels. The market segments for products like their robotic lawn mower are of varying magnitudes, but overall an increasing demand of the products have led to a rapid growth in sales the recent years and an undisputed market leading position (Husqvarna Group, 2018a). Husqvarna Group are also the European leader in watering products as well as a global leader in cutting equipment and diamond tools (Husqvarna Group, 2018b). For the future they have a set of targets which consist of becoming the best place to work at, to inspire and build a sustainable supplier base, to lead their industry in safety across the value chain, to build a platform for their teams to engage in local communities, and to decrease their carbon emissions (Husqvarna Group, 2018a).

1.3. Problem Description

Commodity prices are rising as natural resources are becoming scarcer, and environmental goals are set from both the EU and the UN to promote sustainable development in modern industries (Taranic, et al., 2016). Beyond those spurred to action by these factors, a myriad of companies has already begun their own journeys on exploring remanufacturing for economic benefits or competitive advantages (Kaya, 2010), some basing their entire business idea on it. Alternative business models, such as selling mainly the function instead of the product through e.g. leasing, give further interest to the recollection and reuse of products and in turn possibilities for profit and positive climate impact (Kurilova-Palisaitiene, et al., 2018).

Husqvarna has started multiple innovative projects focused on sustainability, among them the Husqvarna Battery Box concept (Husqvarna AB, 2019). The company is now interested in taking further steps towards a circular economy and investigations of the possible financial and environmental benefits a remanufacturing implementation could bring to their business. This proposes the challenge of assessing how this process conceivably can be incorporated, through choices of production and location, together with an already existent forward supply chain.
1.4. Purpose and Research Questions
The purpose of this project is to investigate how to incorporate remanufacturing of robotic lawn mowers into an existent forward supply chain, and further to evaluate the economic consequence of such an incorporation.

This will be realized by proposing and evaluating multiple alternatives for remanufacturing at different locations in the extended supply chain.

Research Questions:

1. What type of production system is most suitable for remanufacturing given a certain quantity?
2. Which prerequisites in terms of operational, logistics and labor factors do different locations in the supply chain have for a remanufacturing process?
3. What is the economic feasibility of remanufacturing for the locations in the supply chain?

1.5. Delimitations
To limit the scope of this project, the company Husqvarna and the Swedish region are the target of analysis from which the results can be adapted to other settings and international regions. Only products of the Husqvarna brand and product family are examined. For the calculations performed in the analysis, data on model 220 of Husqvarna’s Automower product family are used. This model was selected as data was available and as it is approaching the end of its product life time.

The potential remanufacturing locations in the supply chain are limited to Husqvarna’s current dealers, warehouses, a possible new location in Sweden, the international manufacturing plants, and in addition to this the alternative of a third-party company. Only combinations of production systems and locations in the supply chain deemed relevant for Husqvarna are investigated. The resulting impacts on and of the suppliers is not considered.

This project does not consider the market aspect of customer willingness to buy a remanufactured robotic lawn mower. It does not either consider production planning, or product design and materials. Both the subjects of customer willingness to purchase and product design for remanufacturing are handled by other projects concurrently carried out in collaboration with this project.

Even though Husqvarna are interested in the environmental aspects of remanufacturing as well, these factors are not the focus of this investigation.
2. Method and Methodology

The following chapter describes the selected method of this study, which was used to answer the previously stated purpose and research questions. The selected data collection and analysis methods are presented along with discussions of how the results and conclusions will be presented. This chapter also covers how the data and the results are validated as well as how to ensure that the study has a high reliability.

2.1. Research Phases

An overview of the project’s workflow is presented in Figure 2, the steps are further outlined in the following contents of this chapter.

![Figure 2 - Method overview.](image)

2.2. Methodology

Quantitative scientific methods follow a logical process governed by causality, exemplified as controlled experiments with validity measured inherently to the process itself, while qualitative methods examine social constructs and perceptions in favor of one objective truth (Croom, 2010). A primarily qualitative method was used for this study. The bulk of the empirical data was qualitative in nature as the primary method of data collection was interviews pertaining to individuals’ perceptions of the locations in the supply chain, their prerequisites and the product itself. Quantitative data available for collection and analysis fortified and complemented the qualitative reasoning in determining the results of the study.

Normative (or descriptive) studies asks ‘what’ questions in trying to express the current state of a phenomena while explanatory studies venture deeper into the ‘why’ and ‘how’ of its occurrence (Gray, 2013). This study incorporated both normative and explanatory elements as it in its purpose set out to both define what alternatives that were available and following this to explain why these alternatives were viable in terms of economic feasibility. Consecutively the first and second research questions were normative and explanatory in nature, originating in defining set arrays of possible alternatives and then proceeding to explain the suitability of the array’s elements to the studied remanufacturing process. The third research question more distinctly aimed to, with explanatory reasoning, explain the expediency of the presented alternatives.

Building of logically sound arguments is of great importance to the conclusions of scientific reports. All three sets of logic are built on the same three components but apply them in a different order; deduction starting with a rule and applying observations to draw conclusions of the results, induction that for an initial observation through testing conclusions attempts to find the rule that governs the interaction, and finally abduction starting out from a conclusion and testing different rules to assess the preconditions (Karlsson, 2010). Both abductive and deductive reasoning were applied throughout...
the study. In answering the research questions deduction was utilized in combining presented theory with the collected empirical data. An abductive approach was taken when examining the final research question, turning the question on its head and exploring with probable reasoning what production systems and locations would be preferable for a profitable scenario, as an option to deducing the economic impacts of the alternatives.

This thesis focused on the present possibilities of remanufacturing for Husqvarna’s robotic lawn mowers specifically. Therefore, it was performed as a single case study, case studies being the foremost method of choice when posing explanatory questions in a real-life environment (Yin, 2009). As such, the qualitative research method should have been a perfect fit for the study, as strengths of case study research include the possibility of examining the phenomenon in its natural setting on a deeper level, exploring further the ‘why’, ‘what’ and ‘how’ (Benbasat, et al., 1987; Yin, 2014). Applying such an approach could however present risks of observer bias and does hinder the generalizability of the results to some extent (Voss, 2010). However, as this study was a unique case meant to primarily serve as decision support for Husqvarna specifically, and consisted of applications of theoretical models and analysis tools, the overall scientific benefit to the field of operations management itself would already be limited. However, other industrial companies with similar interests or situation could still benefit from the study results.

2.3. Data Collection
Collection of data was performed utilizing two primary methods of literature study and interview study, both further detailed below.

2.3.1. Literature Study
Published and peer-reviewed articles together with other scientific literature (e.g. conference proceedings, books and reports) were the primary data sources of material for the theoretical frame of reference. An initial base of articles was provided by the project tutors knowledgeable in the field of remanufacturing. Further searches for articles were made with Google Scholar and through the Linköping University library resources. Searches included mainly the term ‘remanufacturing’ in combination with other words such as; ‘feasibility’, ‘forecasting’, ‘supply chain’, ‘plant’, ‘facility’, ‘location’, ‘sales’, ‘profit’ or ‘redistribution’. Other terms as ‘circular economy’, ‘production systems’ and ‘reverse logistics’ were also used in searches. A snowballing approach was then taken, through relevant articles and state of the art defining literature reviews continuing searches to referenced articles. The reverse citing function of Google Scholar was also used in a similar manner to find more material.

2.3.2. Interview Study
Interviews provided data for the description of the current state. Multiple interviewees from different locations in the supply chain were targeted, ranging from higher management to retail, to attain a full overview. Possible venues of communication were face-to-face, e-mail, telephone and video conference calls. The interviews followed a semi-structured layout supporting construct validity (Gammelgaard & Larson, 2001). The semi-structured interview style was chosen as it allowed for increased interaction between the interview parties, giving additional context to the discussed questions, while still keeping focus on the subject at hand. As such, interviews of this study consisted of prepared questions (see Appendix 1) with the possibility to expand on answers as well as delve deeper into subjects of further interest or new questions that may have appeared. During the
interviews both investigators participated, where one mainly asked the interview- and follow-up questions while the other took notes. The interviews were also recorded where possible to help ensure the reliability of the presented data. Further information about data validation and biases are covered in section 2.6.

The interview data were both of a primary and secondary nature, depending on the available sources and their connections to the discussed subjects. Data of contextual interest were; the current structure of the production and supply chain of the product, production metrics for factors as labor and equipment costs, and managerial plans for the product such as desired location, scope and remanufacturing process. Quantitative data were collected for use in a net present value (NPV) analysis with a discount rate determined by Husqvarna’s rate of return on investments, focusing further on points such as costs for material, labor, facility, tools and transportation as well as possible profits. When unavailable, the data was gathered if possible or otherwise estimated either with reference values or through discussion with an appropriate contact at Husqvarna.

2.3.3. Research Question Approach
The research questions utilized theoretical and empirical data to various extents. This is presented in Table 1. Answers to the first research question were mostly based on the literature study, where the literature study provided theoretical information about the investigated fields. This was then analyzed mostly independently of the interview study to achieve a general interpretation and conclusion. The second and the third research questions were more directly connected to Husqvarna, therefore the data from the interview study was at focus, while the literature study provided the tools to interpret the empirical data.

<table>
<thead>
<tr>
<th>Research Questions</th>
<th>Method for Data Collection</th>
</tr>
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<tbody>
<tr>
<td>RQ1</td>
<td>Literature Study: Major</td>
</tr>
<tr>
<td></td>
<td>Interview Study: Minor</td>
</tr>
<tr>
<td>RQ2</td>
<td>Literature Study: Minor</td>
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<td>Interview Study: Major</td>
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<tr>
<td>RQ3</td>
<td>Literature Study: Minor</td>
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<td></td>
<td>Interview Study: Major</td>
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2.4. Analysis Method
The presented frame of reference was the basis of the analysis to interpret the collected empirical data about the current state of Husqvarna, and the different approaches for remanufacturing. Suitable production systems were presented based on the identified required attributes and remanufacturing scope. Thereafter the production systems were interweaved with the identified approaches and locations for remanufacturing to determine which production systems were appropriate for each alternative.

Alternatives in terms of location that were investigated were the international manufacturing plants, the main warehouse, the dealers, a third party and a new location. Their advantages and disadvantages were listed in multiple SWOTs, as it is a simple and widely used method for approaching complex problems (Madsen, 2016). However, the SWOT requires an extended analysis to prevent a false sense of confidence (Pickton & Wright, 1998). This was the reason for an introduction of another analysis method which takes on the results from the SWOT to investigate them further.
The most appropriate alternatives identified through the SWOT analysis were selected for an NPV-analysis, where all types of relevant costs were included either as actual values or estimations. This tool was selected due to its simplicity, understandability, and widely accepted use in investment decision making (Espinoza & Morris, 2013; Law, 2004; Magni, 2009; Pries, et al., 2001; Tang & John Tang, 2003; Žižlavský, 2014), especially so in theoretical or academic contexts (Agnes Cheng, et al., 1994; Berkovitch & Israel, 2004; Pasqual, et al., 2013). However, care must be taken as the model has several known flaws; not valuing flexibility (Brookfield, 1995; De Reyck, et al., 2008; Feinstein & Lander, 2002; Keswani & Shackletón, 2006), problems in dealing with uncertainty (Brookfield, 1995; Hanafizadeh & Latif, 2011; McSweeney, 2006) and in some cases having difficulties in selecting the more beneficial alternative (Berkovitch & Israel, 2004; Haley & Goldberg, 1995). Still, as the purpose of this study was to investigate existent alternatives and their respective economic feasibility no detailed comparisons were required. The time frame focused upon for the NPV-analysis was short as recommended by Myers (1984) to ease the understanding and analysis of the resulting values, furthermore to limit the uncertainty of estimated data and the impact of limited flexibility.

As the data required for the net present value analysis was of sensitive nature to the investigated company, no real-world data were presented in the report for this task. The resulting values from the calculations were adjusted in such a way that no real-world data could be derived from them, while keeping the integrity of the succeeding reasonings. As such the discussions, analyses and conclusions that originate from the calculation results remained the same as if no adjustment had been made.

A sensitivity analysis is suitable as a complement to NPV, because it includes potential distributions of the NPV outcomes (Triantis, 2005). It was conducted along with the estimations to minimize errors (Gallo, 2014) and determine to which extent the investigated factors affected the profitability of remanufacturing.

2.5. **Results, Conclusions, Discussion and Recommendations**

Structure and course of action for the later chapters were as follows: The presented results consisted of production systems fitting for remanufacturing and different approaches for remanufacturing which could be performed for or by Husqvarna, as well as their economic feasibility. The analysis which was assembled upon the theoretical framework and the current state, together with the SWOT and NPV models, built the foundation from which the research questions were answered, and from which conclusions were drawn. These were used to form recommendations for Husqvarna; how, if, and why they should or should not approach remanufacturing.

Chapter 8 include discussions on the limits of this study, and how other methods or data could have affected the results. Ethics and sustainability were also discussed, aiming to determine whether there were any unethical or unsustainable aspects of this study. The chapter also contains discussions on generalizability for the work’s results and how further research can be conducted in this field.

2.6. **Validity and Reliability**

All steps of the project were presented in this chapter to ensure that similar studies can be conducted. Furthermore, when conducting interviews, the answers were documented along with the interview questions. Afterwards, when the interview material had been summarized, if possible the interviewee was contacted to validate that the presented data were correct. The same interview questions were also asked to multiple interviewees to triangulate and ensure that the data were valid. This counteracted
inclusion of biases and personal opinions in the collected data (Patton, 1999). In the cases where data conflicts occurred, the interviewees were contacted for further explanation, and the question was asked again to another interviewee. For both validity and reliability reasons, the questions for each interview were adapted to the area of expertise of the interviewee.

The suggested approaches to remanufacturing were validated by ensuring that the presented analysis and conclusion were reasonable compared to Husqvarna’s current production of new robotic lawn mowers and to how other companies, like Inrego and Toyota, have started with remanufacturing. The presented remanufacturing process must also be reasonable and reachable. This was accomplished by continuously communicating and cross-checking preliminary findings with Husqvarna during the study.
3. Frame of Reference
In the following chapter the theoretical core of the report is presented, including the concepts of circular economy and remanufacturing, manufacturing outputs and production systems, as well as the selected analysis tools SWOT and NPV.

3.1. Circular Economy
The circular economy concept has garnered multiple definitions over its lifetime, the shared idea being that of a cyclical closed-loop system (Murray, et al., 2017). This is achieved by prolonging the use of products, cycling materials when they reach the end of their life, and reducing waste by design – all in the aim of producing a regenerative system (Brennan, et al., 2015; Ellen MacArthur Foundation, 2017b; Fischer & Achterberg, 2016; Geissdoerfer, et al., 2017). Successful implementation would in comparison to linear economy mean a resilient system with great environmental and societal sustainability effects in excess of access to emerging business models (Ellen MacArthur Foundation, 2017b; Murray, et al., 2017).

When transferring strategies towards a circular economy, it has been argued that to facilitate the process an overarching vision focused around the concept’s elements should be implemented before redesigning of products and new business models are actualized (Boekon, et al., 2016). The first step of ten in Fischer & Achterberg (2016) for creating circular business models in practice somewhat mirrors this idea but suggests that the nature of the company’s core activities should influence the positioning towards a circular strategy. They highlight four areas that could act as the foundation for a circular business model; network organization, circular design of products, optimal use of products and value recovery – the last further divided into the possible areas of repair, reuse, refurbish, remanufacture and recycle.

3.2. Remanufacturing System
A remanufacturing system is defined by Östlin (2006) as a system where used or discarded products are collected, remanufactured, and then reintroduced to the market. The remanufacturing system encompasses all stakeholders; the customers, suppliers, and the remanufacturer. Figure 3 shows how materials flow between these stakeholders in internal and external processes. Remanufacturing of the product itself as a part of the remanufacturing system is performed by the remanufacturer in a remanufacturing process. Within the phases of the remanufacturing process the product goes through multiple stages which Sundin & Bras (2005) present as cleaning, inspection, storage, disassembly, repair, reassembly and testing. The order of these are not fixed, the remanufacturer decides what stages are necessary and in which order they need to be performed (Sundin & Bras, 2005; Östlin, 2006). It is common that the cores are collected at many locations and then sent to one processing facility (Gupta, 2016) where the remanufacturing process is conducted in a factory environment similar to how the original product was produced (Lund, 1984). As all remanufactured products should be at an “as-new” level or better in quality, testing of these products is commonly more rigorous than the usual random test sampling of original production (Gallo, et al., 2012).
The remanufacturing process can be performed by three types of remanufacturers: original equipment manufacturers (OEM), independent remanufacturers (IR) and contract remanufacturers. The first type is when the OEM is responsible for both manufacturing of new products and remanufactured products, while the second is when an IR acquires cores and remanufacture them. This can be done in collaboration with an OEM, but not necessarily. The third type delivers remanufacturing as a service to the customer. The service can be provided by either the OEM or an IR, but the customer owns the product throughout the whole process. With contract remanufacturing the product is restored to the conditions stated in the terms and conditions of the service contract. (Lund, 1984)

When the remanufacturing process is handled by an OEM it can either be through a hybrid or a non-hybrid remanufacturing system. Hybrid system is the term for when remanufacturing is performed in parallel with manufacturing using the same resources (Wei, et al., 2015). This system adds further complexity, as described by Thierry et al. (1995) for the case regarding CopyMagic, because a hybrid system must have the capability to handle the different capacities, lead times, substitutable demands and costs of the different products (Wei, et al., 2015). Therefore, a non-hybrid system is more commonly used.

In implementing a remanufacturing system, the aptitude of using present knowledge and resources greatly impacts the resulting productivity of said system (Dowlatshahi, 2005).

### 3.2.1. Benefits of Remanufacturing

Some of the reasons why companies want to use remanufacturing in their value chain is that the remanufacturing process can provide reduced production costs, improved brand image and protection of the aftermarket (Toffel, 2004). Labor and resources for the production are often cost heavy posts in remanufacturing, and to achieve profitability it is crucial that the purchase price of the core is at a satisfactory level for both the customer and the remanufacturer (Kalverkamp, 2018). The reason for a reduction in total production costs, even though a price for a core must be paid, is that many of the
components of the core can be reused or refurbished instead of completely replaced by a new equivalent. This lowers the use and cost of raw materials (Kerr & Ryan, 2001; Toffel, 2004; Östlin, et al., 2008), which benefit economic factors of the remanufacturer (Demirel & Gökçen, 2008; Fleischmann, et al., 2000).

Thierry et al. (1995), Seitz & Peattie (2004) and Östlin et al. (2008a) state that remanufactured products are sold at a reduced price, but Östlin et al. (2008) add that this will not make remanufacturing non-profitable, since less new materials are used in the process. The reduced price is necessary because customers have a lower willingness-to-pay for them since the remanufactured products are not exact substitutes (Abbey, et al., 2019; Wei, et al., 2015). However, there are indications that a discounted price will linearly increase the attractiveness of a remanufactured product (Abbey, et al., 2015b). The remanufacturing process will benefit both the remanufacturer and the customer with reduced costs (Östlin, et al., 2008). It is also possible to broaden the competitiveness on the market with remanufacturing, because it can be used by premium brands to compete with cost against low cost competitors, by delivering a premium product at a reduced price (Atasu, et al., 2008a). Further discussions on the market of remanufacturing can be found in subsection 3.2.3.

Sundin & Lee (2011) list in their literature study multiple benefits of remanufacturing for many different types of products. These benefits span from less energy and material consumption to less greenhouse gases and wastes. One example of this is the research conducted by Kerr & Ryan (2001) where their study of photocopiers shows that it is possible to significantly reduce the energy and water consumption in addition to the reduction of material use by remanufacturing compared to manufacturing. The wastes from the product and CO₂ emissions were lowered as well in the process. They also show that the benefits were increased further if the product was designed for remanufacturing.

Research conducted by Abbey et al. (2015b) show that remanufactured products attracts customers who consciously look for environmentally friendly products. Taking greater responsibility for the environment and satisfying the customers may be done by promoting product recovery programs such as remanufacturing, which will improve the image of the brand (Toffel, 2004). Remanufacturing companies themselves state that due to their remanufacturing processes they both experience environmental benefits (reduced emissions and usage of resources) and social benefits (creating jobs and making their products accessible to more consumers) (Sundin, et al., 2016). However, a positive environmental impact has been found to be more likely when the OEM shoulders the remanufacturing process rather than an independent remanufacturer (Örsemir, et al., 2014).

Remanufacturing works best when the remanufacturer and the customer are both benefiting from the process (Östlin, et al., 2008a). Some companies establish exchange cycles, which require the customer to return their core if they want to buy a remanufactured product (Seitz & Peattie, 2004). This protects the aftermarket by preventing customers to return the core to competitors, while also benefiting the customer by providing a remanufacturing service. The returned core will satisfy the demand of the remanufacturer and keep the cores from appearing on the market (Östlin, et al., 2008a). Exchange cycles will increase the communication between the OEM and the customer, as the information about why and how the product broke will be provided directly to the OEM. This allows for further improvements of the product in terms of quality (Lund, 1984).
3.2.2. Challenges of Remanufacturing

Lundmark et al. (2009) state in their literature review that the main challenges of remanufacturing are complexity (in handling a large number of suppliers and issues with redistribution) and uncertainty (in both the supply and collection process of the cores as well as the demand of remanufactured products). However, they also emphasize that the challenges a company faces are often company specific, and that general challenges are not always the most significant aspects. Many decision models for remanufacturing do not consider the uncertainty aspect in terms of lacking information, even though the uncertainty level is usually high for remanufacturing (Goodall, et al., 2014).

The human dimension and product proliferation are two areas of challenges that Seitz & Peattie (2004) cover in their research. Lund (1984) states that the human dimension normally covers the labor-intensive activities of the remanufacturing process. These are disassembly, inspection and re-assembly, and they require skilled workers. Seitz & Peattie (2004) explain that product proliferation deals with how the remanufacturing process should have the capability to handle many different product variations. If the product proliferation aspect is complex, then the human dimension will require workers with even higher skill level. This will both increase the labor cost and the risk that errors occur in the process (Lund, 1984). Furthermore, if a new product is further developed with new functionality or design, then it will put stress on the remanufacturing process, because it must handle the added variety (Seitz & Peattie, 2004).

The importance of products that are designed for remanufacturing is stressed by Lundmark et al. (2009). They mean that suitable design has the ability to lower the complexity of the processes and the requirements on the labor. This will also help controlling the technical development and the expected life of the product. Even so, it is not common to consider ease of remanufacturing of a product during development (Kurilova-Palisaitiene, et al., 2018).

Other issues are low profit margins (Dowlatshahi, 2005; Sundin, et al., 2016), the demand rates of remanufactured products being usually lower than that of new products (Seitz & Peattie, 2004), and that the forecasts of demand are uncertain (Gupta, 2016; Seitz & Peattie, 2004), which is even more significant if the market is immature to remanufactured products (Lundmark, et al., 2009). The uncertainty makes the production planning complex, and due to low production volumes, it is difficult to apply mass production principles which could lower production costs (Seitz & Peattie, 2004).

In sales, there is also an important issue in the form of a cannibalization effect that may occur if the remanufactured product starts competing with other products of the company, possibly reducing profits depending on costs and retail prices of the different products, and creating internal problems with perception on remanufacturing (Lebreton, 2006). An increased amount of product similarities implies a higher risk of cannibalization, and therefore new business extensions should strive for targeting new market segments and inheriting other product functions (Buday, 1989; Copulsky, 1976). When differences between remanufactured and original products of the same model are clearly apparent the risk of cannibalization further increases (Atasu, et al., 2010), while the absence of differences empowers the benefits of remanufacturing further (Ferrer & Swaminathan, 2006).

Research shows that the risk for cannibalization is tangibly higher for commercial (or business to business) products than for consumer (or business to customer) products where the risk was perceived to be minimal (Guide Jr & Li, 2010). Furthermore, researchers claim that with high degrees of
cannibalization combined with limited access to product cores, the remanufacturing process has slim chances of being profitable (Atasu, et al., 2008b). Finally, this kind of cannibalization is not to be confused with the process of cannibalization, which instead can be described as selective disassembly (Lebreton, 2006).

There are market aspects of remanufacturing, such as disgust and other negative attributes which the remanufacturing process must overcome to prevent that the attractiveness of the product will be decreased (Abbey, et al., 2015a; Abbey, et al., 2015b). However, for technology products the negative perception in terms of disgust or repulsion of remanufactured products is low compared to household or personal care products (Abbey, et al., 2015a).

3.2.3. Market of Remanufacturing

Chierici & Copani (2018) state that there are five revenue schemes which affect the purchase behavior of the customer. These are; sale, leasing, renting, pay per use, and pay per functional result. Models where the manufacturer is the owner of the product which the customer is using, such as in leasing and renting, the products are often suffering from more wear and tear than if the customer would own the product which will lead to more costs for the product owner (Kuo, 2011). The reason for this is that the user is less careful with a product if they do not own it themselves.

Product-service systems (PSS) can be defined as “a mix of tangible products and intangible services designed and combined so that they jointly are capable of fulfilling final customer needs” (Tukker & Tischner, 2006). Such a business model encourages circular design and core control (Fischer & Achterberg, 2016) and gives both economic and environmental benefits if applied together with remanufacturing (Kurilova-Palisaitiene, et al., 2018). The research conducted by Yang et al. (2018) show empirical evidence that PSS business models with remanufacturing can help companies in their transition to a more circular economy. Furthermore, a company will have more control over when cores arrive to the remanufacturing site if they are sold as a function instead of as a product, as well as the inventory holding cost for the remanufacturer will be less because the customer keeps the product until the remanufacturing process starts (Sundin & Bras, 2005).

Gan et al. (2017) show that a closed-loop supply chain with two separate sales channels for remanufactured and new products has the potential to be more profitable than a single channel. In their case the second channel was a direct channel for remanufactured products controlled by the manufacturer which enabled them to target different market segments with the two channels, and thereby increasing the number of sales. Atasu et al. (2010) mean that the market segments for remanufactured products are mainly divided into two customer types, prioritizing either the pure function of the product or its relative newness, the latter type devaluing remanufactured products in favor of newly produced ones.

Companies with remanufacturing activities are usually more profitable than those without, except for when the market for remanufactured products is relatively small compared to new products (Yalabik, et al., 2013). How profitable remanufacturing is depends, however, on many factors. Pricing and market segmentation are two factors which affect the management of new and remanufactured products (Kovach, et al., 2018; Mitra, 2016). Even if the remanufacturing process is not a very costly process, it can holistically turn out to not be profitable for a company (Kovach, et al., 2018). The reason for this is that a remanufactured product along with new products could decrease the
differentiation of the product which in turn could decrease the market segmentation and the profitability. Debo et al. (2005) lift the importance of the consumer as a deciding factor, suggesting that the more customer focus is on lower-end products, the poorer prerequisites exists for an overall successful remanufacturing process.

Subramanian & Subramanyam (2012) investigate several key factors in pricing of remanufactured products through their empirical study of electronics online sales. Their study shows a mean price differential of 27 percent with a standard deviation of 19 percentage units between prices of original and remanufactured products. The upper end of the resulting price reduction between 8 to 46 percent is similar to the mean reduction of approximately 50 percent found in the report by Sundin et al. (2016) or the 30 to 40 percent reduction stated by Giutini & Gaudette (2003) for remanufactured products of all sectors.

Furthermore, it is shown that seller reputation significantly impacts pricing, also in favor of other factors like warranty alternatives. Lastly, remanufactured products sold by OEMs, or by them authorized parties, are commonly done so at a higher price than the same products sold by outside third parties. (Subramanian & Subramanyam, 2012)

3.2.4. Core Acquisition Management

As previously mentioned in subsection 3.2.2 one of the greatest challenges of remanufacturing is uncertainty. A very commonly encountered problem in this regard is uncertainty regarding the available quantity (Kurilova-Palisaitiene, et al., 2018) and quality of retrieved cores (Ferrer, 2001; Kurilova-Palisaitiene, et al., 2018). Rate of returns vary vastly between different products, commonly being below 30 percent (Teunter, et al., 2008) while online and catalogue sales typically have higher returns than other sales (Gentry, 1999; Guide Jr, et al., 2006). Furthermore, not all of the returned cores or even their components will then be usable in the remanufacturing process, due to factors as wear or damage (Krupp, 1993), and inspections will be needed if such wear is not predictable to avoid the reuse of components that might fail or prevent useful components from being lost (Ferrer, 2001).

Access and management of cores are issues specifically highlighted by remanufacturing companies (Sundin, et al., 2016). This highlights the necessity of core acquisition management, which is defined by Wei et al. (2015) as the process of “managing the uncertainties of the return volume, timing and core quality to achieve a better balance between demand and return”. Five parts of acquisition management were identified by them which are presented below:

**Acquisition control** can be used to affect the amounts of cores that are returned to the remanufacturer by changing the buy-back price or deposit when gathering cores in a market driven system. However, the acquisition control process is usually uncertain, which sometimes results in a higher or lower arrival rate of cores than anticipated. When this happens the disposal volume must be adapted to keep the system stable. (Wei, et al., 2015)

**Forecast return** is a technique used to estimate how many cores that will be returned to the remanufacturing facility and when. This process is complex, and the uncertainties are many, but it is critical to understand the return pattern to perform a successful remanufacturing process (Wei, et al., 2015). Researchers like Clottey et al. (2012) give generalized forecasting models able to be complemented with works like that of Liang et al. (2009) who propose open market relationships for core pricing.
Quality classification is the process where a product is inspected to determine in what condition it is (Wei, et al., 2015). This process is important as it is very likely for a returned core to have some sort of defect or fault (Thierry, et al., 1995). An incentive for return, e.g. a buy-back price, could be based on the identified quality classification which also determine what restoration process that is required to restore the quality of the product (Wei, et al., 2015).

Reverse channel handles how the core is acquisitioned and by whom (Wei, et al., 2015). Either the OEM themselves could manage this process, alternatively enlisting their retailers or a third party for the task (Kaya, 2010; Wei, et al., 2015). However, in a decentralized setting, the retailers are best suited to collecting cores (Savaskan, et al., 2004). Locations where the customer can return a core are denominated as collection centers, and from these locations the cores are eventually transported to a remanufacturing facility where they undergo the remanufacturing process (Melo, et al., 2009). It is possible to implement the entirety of the reverse channel with detached impact from the existing distribution networks, but in many cases the reverse channel is initially interwoven with the original distribution channel (Fleischmann, et al., 2001; Thierry, et al., 1995).

Return strategies are utilized to reduce the uncertainty of the return of cores (Wei, et al., 2015). The return is a stochastic process, which means that the cores will arrive at irregular intervals (Fleischmann & Minner, 2004). Östlin et al. (2008a) identify seven closed-loop supply chain relationships that could affect this process. These are listed in Table 2. They state that these relationships are sometimes used as complements, which mean that they can and will, most likely, coexist. This is something Wei et al. (2015) present as mixed return strategies. The strategies are chosen depending on a trade-off between inventory build-up and future cost savings (Fleischmann & Minner, 2004). Proper return strategies are important for efficient return flows, which in turn are crucial to a remanufacturing process as without them there is no chance of economic feasibility (Ayres, et al., 1997; Guide Jr & Van Wassenhove, 2001).
<table>
<thead>
<tr>
<th>Relationship</th>
<th>Definition</th>
<th>Positive effects</th>
<th>Negative effects</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ownership-based</td>
<td>The customer rents, leases or uses a product-service offering from the seller, who has contract regulated control of the product.</td>
<td>There is a strong link between the remanufacturer and the customer. The remanufacturer has much information about when or if the core should be remanufactured.</td>
<td>The seller is responsible for all maintenance, service, et cetera, which means that the sellers take most risks.</td>
</tr>
<tr>
<td>Service-contract</td>
<td>The customer has a contract with the manufacturer in which remanufacturing is included.</td>
<td>Less responsibility for the seller than in ownership-based. Service, maintenance and remanufacturing can be separated in a contract.</td>
<td>The customer decides when the core is returned, which makes the return rate uncertain.</td>
</tr>
<tr>
<td>Direct-order</td>
<td>Core is returned by the customer. The core is remanufactured, and the same product is returned.</td>
<td>Low stock of cores is needed since the returned core is remanufactured for the customer.</td>
<td>All cores cannot be remanufactured. Different quality cores require different pricing policies.</td>
</tr>
<tr>
<td>Deposit-based</td>
<td>The customer must return a core to be able to buy a remanufactured product.</td>
<td>Win-win situation where the customer buys a remanufactured product, while remanufacturer receives a core. No or short waiting time for customer.</td>
<td>All cores cannot be remanufactured, ratio to returns not 1:1. Must be combined with other relationships. Customers do not benefit from returning a high-quality core.</td>
</tr>
<tr>
<td>Credit-based</td>
<td>Customer receives credit when a core is returned. Credit provides a discount on remanufactured products.</td>
<td>The credit received is dependent on the quality of the core, and it can be increased to increase the number of returned cores.</td>
<td>Can be abused by customers which gather a lot of low-value cores to get credit. High administration cost.</td>
</tr>
<tr>
<td>Buy-back</td>
<td>The remanufacturer buys cores from the customers. Frequently used as a complement to other return strategies.</td>
<td>High return rate from customers and scrap yards. Works well for cores that otherwise would not have been returned.</td>
<td>Difficult to determine the quality of the core.</td>
</tr>
<tr>
<td>Voluntary-based</td>
<td>Core is returned to the remanufacturer for free.</td>
<td>Remanufacturers receive cores for free.</td>
<td>Low motivation for customers to return cores. High risk that cores are returned to competitors instead.</td>
</tr>
</tbody>
</table>
3.2.5. Locations in the Supply Chain

Two general scientific approaches are prominent in suggesting solutions for the facility location problem: mathematical formulations normally expressed as cost minimizations or profit maximizations of the problem and factor assessment (Chen, et al., 2014). Economic sustainability has been the historical focus of the problem, but other sustainability aspects has shown to be important, concentrating on cost only is not viable as other factors impact the performance of the supply chain (Bhatnagar & Sohal, 2005; Dowlatshahi, 2005; Gupta, 2016; MacCormack, et al., 1994). Models like that off Dou & Sarkis (2010) have been developed to incorporate both business and sustainability factors for better solutions to the location problem.

Cheng et al. (2015) discovered with their literature review that most researchers study location problems narrowly with focus on achieving low cost by using an optimization algorithm. The cost difference between the alternatives are often not significant, and therefore other tangible and intangible factors should be considered as well (Cheng, et al., 2015; Schmenner, 1979). These factors range from overcoming proximity to market and tariff barriers to access of knowledge, infrastructure and complementary services (Cheng, et al., 2015).

Further interests for sustainable facilities and therefore also location decisions have sprung from not only the industry, but legislative bodies and the general public as well, to include social and environmental aspects and requirements (Terouhid, et al., 2012). The importance of these interests is expressed through the governmental and customer location factors which alongside logistical capabilities and labor opportunities have shown to be impactful for remanufacturing location decision-making (Lu, et al., 2014). These factors are for example labor skills, available space and public utilities at the investigated locations (Breitman & Lucas, 1987).

The study conducted by Jakubicek & Woudsma (2011) identify 19 factors and list them in order of importance in a similar manner as the study by Karakaya & Canel (1998). Both studies conclude that the availability of skilled workers are of high importance, as well as factors such as proximity to transport infrastructure, cost of land and facilities, and tax rates. Additionally, Jakubicek & Woudsma (2011) found that access to major customers is important. They then identify proximity to other similar businesses and highway visibility as some of the least important factors, while Karakaya & Canel (1998) list availability of unskilled labor and industrial park(s). All these previously mentioned factors are also included in Min & Melachrinoudis’s (1999) study who use them and others to identify the best location for their relocation of a hybrid manufacturing/distribution facility by listing and prioritizing the assumed impact of each factor.

3.3. Manufacturing Strategy

The strategies for companies are often focused on marketing and finance, and secondly on the production. By not prioritizing production the manufacturing plant will not be able to reach its fullest potential (Hill, 1983; 2000). The aim of a manufacturing strategy is to provide a company, along with its corporate strategy, a competitive weapon which can be used to defend its position in the market (Hill, 1983; Skinner, 1969; Wheelwright, 1984). The first edition of Miltenburg’s framework (1995) provides a model with solid connections between manufacturing strategy and production (Säfsten & Winroth, 2002), which has been built upon further in later editions.
3.3.1. Manufacturing Outputs

Manufacturing outputs, or competitive priorities, are the product attributes a company’s production systems can provide to a customer. Miltenburg (2005; 2008) presents six of these; delivery, cost, quality, performance, flexibility and innovativeness. Focusing on all manufacturing outputs simultaneously is not possible, or at least not efficient, and instead a company must define what their highest priorities are to make a trade-off between the manufacturing outputs (Boyer & Lewis, 2002; Garvin, 1987; Miltenburg, 2008, Skinner, 1974; Wheelwright, 1984). The outputs are used to compete with competitors by providing products which qualify for the market (Hill, 1992; 2000; Miltenburg, 2005). If the product qualifies, then its attributes satisfies the expectations of the customer. Some market qualifying products exceed the expectation of the customer whilst also distinguishing themselves from competing products. These leading qualities are called order winning outputs (Miltenburg, 2005; 2008).

Delivery is defined as how reliably the production system can deliver products on time, and the time it takes from order to delivery to customer. Cost is the production cost, which sets the limit of the price that can be extended to customers. Quality depends on whether the production system can produce products which meet the expected specifications within accepted error rates. Performance handles the features of the products. A product with many features, which are distinctive from others and provide additional functionality has high performance. Flexibility allows the production system to adjust for changes in functionality and customer demand rates. The last output, innovativeness, is defined as how fast new products or redesigns of products can be presented to customers. (Miltenburg, 2005; 2008)

Worth to note is that other researchers present different numbers of manufacturing outputs, this perceived as being caused by a lack of unified definitions (Corbett & Van Wassenhove, 1993) or varying scope of analysis (Miltenburg, 2008). The general contents of the presented outputs are however similar.

3.3.2. Production Systems

The purpose of a production system is to provide the required manufacturing outputs (Miltenburg, 2005). The layout of the system, the equipment that is used and in what degree labor is needed depend on what the system aims to achieve. Miltenburg (2005) defines seven production systems which are described below, while manufacturing outputs of each production system are presented in Figure 4.

Job Shop is a production system with a general purpose which has the capability to handle low volumes with high flexibility (Miltenburg, 2005). These systems can produce a wide variety of product types with different process steps and times (Rangsriratratamee, et al., 2004), and it is best suited when the production volume is too low to use other production systems (Miltenburg, 2005). Queues are usually high, and delivery times long, since many different products are using the same general tools and equipment in a functional layout. Some of the advantages of a job shop is that it provides high innovativeness and the production facility can be kept small (Miltenburg, 2005). The machines in a job shop are general purpose, operated by skilled labor, which leads to high flexibility outputs and a comparably high cost (Charles & Hax, 1985).

Batch Flow has a main characteristic in that all production is performed in batches. The production system is adapted in layout from a job shop or cellular organization (Garavelli, 2001). It has the
capability to handle higher production volumes than a job shop and can provide higher competitive priorities than the job shop for all priorities except flexibility and innovativeness (Miltenburg, 2005). One disadvantage is that the physical size of the production system is usually bigger than that of a job shop. A batch flow production system usually produces make-to-order, with an exception of common products. The produced products have many varieties, which means that the equipment is usually not specialized for a specific product, instead there are general tools and equipment in a functional layout (Miltenburg, 2005).

**Flexible Manufacturing System** (FMS) is usually an automated production system with high flexibility, which can operate for long periods of time without inputs from an operator (Miltenburg, 2005). Such a system is generally considered to consist of systems of processing, material handling and storage, and a computer control system which together with the process automation constitutes the most important difference from normal production systems (Chan, et al., 2002). In addition to flexibility, FMS will provide high quality, high performance and low-cost outputs (Miltenburg, 2005). The production system can handle many different product varieties in low volume batches. The batches can be as small as one unit per batch while still maintaining short delivery times, which a normal batch flow system is incapable of. However, an FMS system requires a cellular layout with a line flow of material which then requires automatic machines with specialized tools and a larger facility than a batch flow (Miltenburg, 2005).

**Operator-Paced Line Flow** (OPL) is a line-based production which enables production of larger volumes than the aforementioned production systems, but only for products with lower varieties (Hill, 2000; Miltenburg, 2005). The main advantage of an OPL system is that it provides high performance and utilizes a line flow of which speed is determined by the numbers of operators assigned to the production line, while also keeping the other priorities at a reasonable high level (Miltenburg, 2005). The cost is higher than that of an FMS system, but lower than the batch flow and job shop. The quality outputs it provides, and the required size of the facility, is similar to an FMS system (Miltenburg, 2005).

**Equipment-Paced Line Flow** (EPL) has the same line layout as an OPL system, but in this system the equipment determines the speed of the line instead of the number of operators (Miltenburg, 2005). The equipment used is usually specialized for the task at hand and the required space is large, which means that an EPL system can be costly to build or make changes to. It can produce a few different products in high volumes with high quality output, low cost and short delivery time (Hill, 2000; Miltenburg, 2005). The setup times are long when changing product mix or when design changes to a product is put into production due to the low flexibility and innovativeness outputs of the system (Miltenburg, 2005).

**Continuous Flow** (CF) is usually a fully autonomous production system which produces standardized products in very high volumes with very little to no variations at a fast, continuous pace (Lee, 1992; Miltenburg, 2005). The machines in the system are positioned in a line with buffers in between to handle variations, where the material flow through each work station once in a fixed sequence, which limits the flexibility of the system (Dallery & Stanley, 1992; Lee, 1992). The system provides very high levels of quality, cost and delivery outputs, but lacks performance, flexibility and innovativeness. The system also requires a large facility to fit the whole line layout with the highly specialized equipment (Miltenburg, 2005).
Just-In-Time (JIT) can be a production philosophy which is used to improve on the aforementioned production systems, or its own distinct system. One of the characteristics of JIT is that all materials, the products and equipment used must be available when needed, or just in time to be used without delays (Miltenburg, 2005). This is achieved by continuous improvements in the production system by eliminating wastes, which can be identified by lowering the available inventory in small steps. Eventually, small problems will appear, which will be eliminated. The benefits of eliminating wastes are reduced costs, improved quality and shorter delivery time (Fullerton & McWatters, 2001; Miltenburg & Wijngaard, 1991).

The implementation of a JIT system is difficult, and it requires highly skilled operators and managers to utilize and further develop the production system. A JIT system has a line layout useful for a product mix, but the volumes it can handle and the flexibility depends on how the system is adapted, which can be from low to medium-high production volumes. The system will provide high performance, flexibility and innovativeness, while it also provides very high levels of delivery, cost and quality outputs. The downside with JIT is that it is a very complex production system, which can be difficult to master. (Miltenburg, 2005)

![Figure 4 - The manufacturing outputs for each production system. Modified from Miltenburg (2008).](image)

### 3.3.3. Product-Process Matrix

Hayes & Wheelwright (1979) have presented a product-process matrix with two dimensions. The production flow is the first dimension, while the product mix and volume make up the other (Figure 5). Being on the diagonal is a natural behavior of a company which utilizes a production system to its fullest potential. Moving away from the diagonal could be beneficial for a company which tries to distinguish itself by delivering manufacturing outputs which competitors cannot. This however is a risky and complex strategy as other complications may occur depending on the company’s approach, such as not being able to produce high enough quantities or losing flexibility (Hayes & Wheelwright, 1979).
Hill (2000) uses a similar matrix in his work, where he emphasizes the importance of choosing an appropriate process based on the two presented dimensions to reach high outputs. The product-process matrix was further developed by Miltenburg (2005), where he combines the production systems (subsection 3.3.2) with the dimensions presented by Hayes & Wheelwright (1979). An additional area off the diagonal of the matrix containing the production systems FMS and JIT was also added. The remaining production systems are positioned on the diagonal in the order depicted in Figure 5.

![Figure 5 - Product-process matrix. Modified from Hayes & Wheelwright (1979) and Miltenburg (2005).](image)

3.4. Methods of Analysis

Previously, in section 2.4 the chosen analysis methods were motivated and presented. In these subsections the tools of analysis for the project are defined and explained.

3.4.1. SWOT

SWOT is a widely used tool to analyze everything from individual ideas to management decisions. It is commonly used because of its simplistic structure which makes disassembling complex problems manageable (Madsen, 2016), and because it can be used to highlight the vital and underlying issues of a bigger obstacle (Chermack & Kasshanna, 2007). A SWOT-analysis incorporates both internal and external factors. The internal factors are used to assess the capabilities of a company in terms of strengths (S) and weaknesses (W), while the external factors are the market situation in terms of opportunities (O) and threats (T) (Barney, 1995; Madsen, 2016).
To some the SWOT analysis seems too simplistic to be used as an actual analysis method, but this is also one of the advantages of the SWOT. The method is basic and therefore it can provide a clear overview of the objectives or challenges which should be considered when making decisions in a business environment. However, the SWOT should be used as a complement to other analysis methods, by taking what it presents and further investigate the results (Pickton & Wright, 1998). This is important to take into account, since the SWOT is only a framework without the capacity to interpret the listed elements by itself (Chermack & Kasshanna, 2007), which then could lead to poor decision-making (Pickton & Wright, 1998).

3.4.2. **Net Present Value**

Net present value (NPV) is a commonly used tool to analyze the profitability of an investment. It is calculated as the value of the resulting cash flows discounted to present day values minus the present-day value of the invested amount according to the following formula (Anupindi, et al., 2012; Holmström & Lindholm, 2011):

\[
NPV = C_0 + \sum_{t=1}^{n} \frac{C_t}{(1 + r)^t}
\]

The cash flows in the formula are represented by \( C_t \), where \( t \) specifies the time of the cash flow while \( n \) limits the sum to the expected economic duration of the investment. The discount rate \( r \) sets the percental demanded return of the investment (Anupindi, et al., 2012). When comparing investments, the investment with the highest NPV is classified as the most profitable. The investment will not result in a profit if the investment has a negative NPV (Holmström & Lindholm, 2011).

NPV can be used in most cases, but there are some weaknesses which must be considered such as irreversibility, uncertain results and competitiveness (Fox, 2008). Many investments are classified as a sunk cost, an irreversible cost, which means that the initial investment cannot be cancelled or sold without losing a significant part of its value. The NPV does not consider effects from delaying an investment and will therefore miss out on other opportunities if the technology or the preconditions improve in the future (Pindyck, 1991).

Myers (1984) states that all investments will reach an equilibrium in the long run, which means that an NPV calculation should always equal zero if the economic duration of the investment is long. The reason for this is that an investments competitiveness will never last forever, since the competitors will eventually catch up. Therefore, he mentions that the focus of the NPV should be short-term, which also will make the interpretation and understanding of the value easier.

3.4.3. **Sensitivity Analysis**

Sensitivity analysis examines the output of an applied model to determine the impact of the inputs’ respective uncertainty (Bannerman, 1993; Jovanović, 1999; Saltelli, et al., 2008). The inherent uncertainties of a model generally arise either from a stochastic behavior of the examined system or from value estimations (Cacuci, 2003). As investment problems are well-ridden with such uncertainties, sensitivity analysis is an appropriate and necessary tool to improve the decision-making process (Behrens & Hawranek, 1991; Jovanović, 1999). The uncertainty of the investment can be reduced by identifying pessimistic and optimistic values of each input in the sensitivity analysis as well as their impact on the output (Behrens & Hawranek, 1991), but one should be aware of that changing
one factor at a time could lead to that the effects of interactions between variables is not taken into account or missed (Czitrom, 1999; van Groenendaal, 1998).

Effectively for NPV-analysis, one estimated input \( I_v \) part of the cash flow \( C_t \) can vary between the values of \( I_{v-1} \) to \( I_{v+1} \). By introducing a correction factor \( k \) for this input to the NPV-formula one can with appropriate percentage values vary the input within this range for multiple calculations, receiving a spectrum of NPV-values. From this spectrum the relative impact and change of that one input can be discerned. Furthermore, with multiple correction factors for separate or grouped inputs one can investigate simultaneous effects on the net present value. (Jovanović, 1999)
4. Current State

This chapter presents all relevant contextual data collected from the performed interviews.

4.1. Interview Study Summary

To promote readability in the text, references to personal communication have been made through superscript where the numbers correspond to the interviews as presented in Table 3. Roles of the interviewees have been generalized, removing specific departments and unique indicators from their description, to maintain personal integrity. Interview questions can be found in Appendix 1. The interviews that were not recorded either were not pre-planned and sprung from other conversation or were conducted in environments not well-suited to recordings.

Table 3 - Interviews arranged by role.

<table>
<thead>
<tr>
<th>Reference #</th>
<th>Role (without departments)</th>
<th>Date of Interview</th>
<th>Duration</th>
<th>Recorded</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Vice President</td>
<td>21 February, 2019</td>
<td>~33 min</td>
<td>No</td>
</tr>
<tr>
<td>2</td>
<td>Strategy Director</td>
<td>18 February, 2019</td>
<td>~23 min</td>
<td>Yes</td>
</tr>
<tr>
<td>3</td>
<td>Finance Director</td>
<td>21 February, 2019</td>
<td>~18 min</td>
<td>Yes</td>
</tr>
<tr>
<td>4</td>
<td>Logistics Director</td>
<td>22 February, 2019</td>
<td>~24 min</td>
<td>Yes</td>
</tr>
<tr>
<td>5</td>
<td>Sustainability Manager</td>
<td>15 January, 2019</td>
<td>&gt;99 min</td>
<td>No</td>
</tr>
<tr>
<td>6</td>
<td>—&quot;—</td>
<td>8 February, 2019</td>
<td>~30 min</td>
<td>No</td>
</tr>
<tr>
<td>7</td>
<td>—&quot;—</td>
<td>21 February, 2019</td>
<td>~33 min</td>
<td>No</td>
</tr>
<tr>
<td>8</td>
<td>Product Manager</td>
<td>8 February, 2019</td>
<td>~30 min</td>
<td>No</td>
</tr>
<tr>
<td>9</td>
<td>Research &amp; Development Manager</td>
<td>30 January, 2019</td>
<td>~33 min</td>
<td>Yes</td>
</tr>
<tr>
<td>10</td>
<td>Regional Manager</td>
<td>25 January, 2019</td>
<td>~30 min</td>
<td>Yes</td>
</tr>
<tr>
<td>11</td>
<td>—&quot;—</td>
<td>8 February, 2019</td>
<td>~10 min</td>
<td>No</td>
</tr>
<tr>
<td>12</td>
<td>Lean Manager</td>
<td>28 January, 2019</td>
<td>~29 min</td>
<td>Yes</td>
</tr>
<tr>
<td>13</td>
<td>Supply Chain Manager</td>
<td>26 February, 2019</td>
<td>~21 min</td>
<td>Yes</td>
</tr>
<tr>
<td>14</td>
<td>After Sales Manager</td>
<td>15 March, 2019</td>
<td>~17 min</td>
<td>Yes</td>
</tr>
<tr>
<td>15</td>
<td>Project Manager</td>
<td>6 March, 2019</td>
<td>~34 min</td>
<td>Yes</td>
</tr>
<tr>
<td>16</td>
<td>Spare Parts Specialist</td>
<td>6 March, 2019</td>
<td>~34 min</td>
<td>Yes</td>
</tr>
<tr>
<td>17</td>
<td>Controller A</td>
<td>21 February, 2019</td>
<td>~18 min</td>
<td>Yes</td>
</tr>
<tr>
<td>18</td>
<td>Controller B</td>
<td>22 March, 2019</td>
<td>~21 min</td>
<td>Yes</td>
</tr>
<tr>
<td>19</td>
<td>Dealer A</td>
<td>7 February, 2019</td>
<td>~45 min</td>
<td>No</td>
</tr>
<tr>
<td>20</td>
<td>Dealer B</td>
<td>14 February, 2019</td>
<td>~26 min</td>
<td>Yes</td>
</tr>
<tr>
<td>21</td>
<td>Dealer C</td>
<td>14 March, 2019</td>
<td>~19 min</td>
<td>Yes</td>
</tr>
<tr>
<td>22</td>
<td>Dealer D</td>
<td>8 April, 2019</td>
<td>~28 min</td>
<td>Yes</td>
</tr>
<tr>
<td>23</td>
<td>Commercial Rental Entrepreneur</td>
<td>16 April, 2019</td>
<td>~31 min</td>
<td>Yes</td>
</tr>
</tbody>
</table>

4.2. Product Details

All components of the robotic lawn mower are designed to endure 10 000 hours of workload (or approximately eight to ten years) without service, except for parts intended for wear and replacement, and the battery which has a four-year life-span.\cite{8,9,12} Most products seem to achieve these requirements, unless used under heavy stress in some commercial environments\cite{8,23} or if a major fault is found. When major faults are found they usually originate from the manufacturing process or from customer misuse (commonly water damage from improper cleaning or if the mower has gotten stuck in a wet
environment). Without such conditions the mower has a real-world perceived life span of eight to fifteen years according to Husqvarna and one dealer, and seven to ten years according to other dealers, with a minimum of five years. However, after an active product life time of three to four years the inherent value of the mower begins to drop significantly.

Most of the robotic lawn mowers value lie in the electronics which are the most expensive components; firstly, the circuit board, followed by engines (propulsion, cutting and adjusting for certain models), battery and power supply unit. Beyond the cutter blades, bearings, seals, and the plastic body, these more expensive parts are the ones experiencing the most wear and tear, being the other parts commonly replaced at service. The lawn mower core does not have much value after the battery, motor and circuit board have been removed. Other components, such as the chassis, the wheels and the plate on the underside of the mower which holds the cutter blades last much longer, but they are also much cheaper to replace.

### 4.3. Supply Chain

Husqvarna have two main flows of components from their suppliers. One goes directly to the factories where they themselves are responsible for the daily planning and usage, while the other flow is more oriented towards to aftermarket activities and spare parts where the demand is centrally controlled and distributed between warehouses. There is no long term finished goods storage at the factories that produce the robotic lawn mowers, but when a deliverable amount has been produced the products are transported (primarily by truck, some distances are required to be covered by ship) to main storages and distributive warehouses. These main distribution centers serve as a supply hub for the surrounding area, and stores both finished goods and spare parts. The assortment of spare parts is however not complete, only the parts commonly in need of being replaced are kept at the main storage facilities while other components are ordered separately and arrive with truck delivery from the factories like the original product. Figure 6 shows the general structure of the supply chain.

![Figure 6 - Husqvarna supply chain.](image)

The main storage facilities are located in many of the countries where Husqvarna sells their mowers, a prime example being the facility in Laichingen, Germany. In Sweden the main distribution center and spare part warehouse are located in Torsvik, in close proximity to Husqvarna’s main hub, and are run by third-party companies like most of the Husqvarna warehouses. Currently the full capacity of the spare parts warehouse is utilized and extra facilities are sometimes rented to house excess articles, but the availability depends on consumption and forecasts. Generally, the spare part availability is better than 95 percent, and spare parts should be available for a product up to about ten years after production has ended.
In excess of the main distribution centers there in rare cases exists smaller, local warehouses if a need for them has been identified. On the other hand, Husqvarna are working on the possibility of large dealers and intermediate warehouses receiving direct deliveries instead of the parcels being re-routed by a distribution center. There has been some observed problems with deliveries to the dealers, due to an old-fashioned, rigid and slow flow of products which could be improved upon with closer cooperation and communication between Husqvarna and their dealers.

4.4. Dealers and Service
Husqvarna has about 300 dealers for robotic lawn mowers in Sweden, see Figure 7 for approximate locations (each step of increase in size of dot in the figure corresponds to approximately ten additional dealers in proximity). There are three different levels of contracts possible between Husqvarna and their dealers, depending on store area, profile, available models and more. The levels of contracts give different terms and benefits to the dealers, e.g. weekly free of charge deliveries. In addition to the dealers, there is a concept store in Stockholm which is the only store in Sweden owned by Husqvarna themselves. It acts as a direct link between Husqvarna and their customers by providing sales and service of lawn mowers.

There are three degrees of training for the dealers and depending on their rank they have permission to sell, install and repair different types of robotic lawn mowers. About half of all purchased units are installed by the dealers. It is also the norm for commercial clients to opt for a three-year full-service agreement, where Husqvarna handles all maintenance responsibilities including regular check-ups and seasonal storage, by contracting dealers. Repair and seasonal storage packages are optional and available for all end customers depending on what their dealer chooses to offer. Additionally, in preparation for seasonal storage the dealer often travels to collect the units from the end customers, the end customer only needing to visit the dealer when they wish to reclaim their machine.
4.4.1. Service Process

Service inspections are carried out by the dealer with the aid of a service checklist, pertaining the necessary steps and further information to the maintenance worker.\textsuperscript{9,20,21,22} The process in its current state is arranged somewhat as if leaving a car for service.\textsuperscript{9,22} Some of the steps are however only stated in general outlines, where the exact execution and extent of the task is left to be decided by the service worker.\textsuperscript{19,20,22}

During the repair process at the dealer, the products are cleaned, inspected and repaired\textsuperscript{10} (see Figure 8), where the cleaning process is usually the most time-consuming.\textsuperscript{8,20} Preemptive repairs are not as common but performed by some.\textsuperscript{23} An important step in the service process is connecting the machine and running through an auto checking software which outputs a comprehensive report on all functions of the mower. Generally, errors are easy to perceive as parts meant for wear show obvious signs of use and internal faults will give an error code to the user. After the service the customer should receive a clean and fully functional unit. Currently all models also receive software updates, but this is being phased out for some older models no longer in the same need of any updates.\textsuperscript{9}
To perform service of the mower some specialized tools are needed, however, most service steps can be performed with common tools, except troubleshooting and system upgrades with Husqvarna’s software solution. For the cleaning process some of the dealers have constructed their own warm water cleaning machines, while others use manual cleaning with simple available equipment such as water and compressed air. To be able to open the mowers a PIN-code is necessary, and therefore all the dealers are required to have a computer system available near the service station of the mower.

In recent years, the technical development of the dealers has increased, because it is a requirement to be able to handle the mowers, and because it benefits the dealers in other areas as well.

4.4.2. Service Differences

Different robot models are similar in design and function, and the biggest differences lie in their software. Older models however do require longer service times than current ones due to the improvements in design in more recent machines. All interviewed dealers claimed that a normal service process takes between one to two hours, while the commercial rental entrepreneur stated that a thoroughly performed service process requires at least half an hour longer time. For some dealers, older and simpler models however take between 20 to 50 percent more time to process – thereby also resulting in a more expensive service, while the required time for service is about equal for all models at other dealerships. One dealer stated that a service worker will usually learn how to perform service of a lawn mower after doing it to two or three machines with supervision, if non-standard steps are excluded, while another dealers service workers were fully proficient after two weeks. To always be able to perform a complete service the worker needs additional knowledge in troubleshooting and reprogramming of the mower.

Some dealers perceive that the service course from Husqvarna consists mostly of theoretical information, without practical examples or tips on how a service should be performed. This leads to a service process which all dealers perform differently, resulting in a non-standardized procedure with different quality and cost outputs. A wish from one dealer was that Husqvarna should present exactly how they want the service to be performed so that all dealers could do it the same way, while another dealer stated that this would only be needed if Husqvarna desired that the quality should be the same regardless of the service provider. On this subject, Dealer C said that any support from Husqvarna...
in creating networks and cooperation between them and the dealers is appreciated, to spread knowledge, marketing strategies or service procedures. Another dealer thought that the service course was inefficient, and it could improve significantly if it contained fewer open discussions, more facts and had more focus on the service workers. Currently, the course includes sales as well, which the dealer thought should be separated from the service course so that their sales workers could take a sales course, while the service workers could focus on the technical aspects. Furthermore, Husqvarna does provide the dealers with a service help line, which is appreciated by some, while others perceive that they are not capable to help with unusual issues due to lack of experience.

4.4.3. Service Profitability

The seasonal storage of the mowers and the service package the dealers are selling are profitable for both them and Husqvarna. The prices of the services are determined by the dealers themselves, which mean that both storage and service have a broad price range. The bigger cities tend to be more expensive, while the countryside dealers are usually cheaper. Husqvarna themselves profit from repairs and service by the selling of spare parts, which in price can vary between models but do hold similar profit margins. Older parts are rising in price due to the lower volumes bought, but generally if bigger orders are placed Husqvarna will receive a discounted price to some extent from their suppliers. The price of spare parts for dealers are also dependent on order size and whether the orders are placed within the discount pre-season period each autumn and spring. There does however exist countless bootleg variants of the replacement parts and to counter this, requirements are imposed on the dealers to only utilize original parts, however it is not a legal requirement. For the lawn mower it is mostly cheaper components such as the cutter blades which are afflicted, but on rare occasions uses of bootleg batteries show up, all which can impact the customers perception of Husqvarna’s product negatively if the bootleg components do not work properly. Currently, the bootleg variants do not have a significant impact on Husqvarna’s profitability, however some bootleg competitors try to exploit the retail market mainly by offering quick delivery and favorable terms.

By offering service of the robotic lawn mowers the need for repairs due to products breaking mid-season is lowered. This benefits the Husqvarna brand as less customers are unsatisfied with the quality of the lawn mower. The repairs of the robotic lawn mowers are currently not overly profitable for the dealers, but there are dealers who perform repairs by changing critical parts as long as they are confident that the product will work as expected afterwards. Dealers though stated that their main income from the lawn mowers was the service offer (or new sales with installation), since the profit margin on the lawn mower itself was small.

4.5. Production

The mowers are produced in factories located in the United Kingdom and the Czech Republic. Current production of the robotic lawn mowers is mainly carried out by assembly in seven different lines and batch wise production, striving for a one-piece flow. The cycle time of the robotic mower production line is one minute, with 50 line operators resulting in a total production time of about 50 minutes. There are lines that have the capability to handle multiple models, but usually different platforms require different lines. Due to low labor costs there has not been a greater need of automated production, but the degree of automation is still steadily increasing and expected to continue to do so.
Some components are manufactured by Husqvarna, mainly all plastic articles in their injection molding process, which must be performed separately from the assembly process. The molding process limits the capacity of the entire line. However, there is no process which takes significantly more time than another. In the production line small changes are conducted continuously. Changes usually do not affect the operators much and should not affect the service personnel or a potential remanufacturing process to any greater extent either.\textsuperscript{9,12} When the platform of the mower is changed, a short course is needed to set the operator up to date.\textsuperscript{12}

For assemblers to qualify for work in the assembly line and to be able to deliver high quality, they need to undergo a learning process which takes three to four months.\textsuperscript{12} It is important for Husqvarna to deliver high-quality products, since their customers expect such a product for the premium price.\textsuperscript{2,12} As a brand Husqvarna represents the values of quality, performance and innovation – important aspects for the users to be able to trust the autonomy of the machine, which will otherwise not be able to fulfill its purpose. Lead time to customer is important and tightly associated with flexibility, with a continuously changing market it is important to be able to adapt and Husqvarna have for this reason implemented “flex” in their production as an approximated buffer.\textsuperscript{9}

In the production Husqvarna measure most things from capacity, and productivity to scrap rates and quality. In the assembly process the operators perform quality checks for each step,\textsuperscript{12} and there is a final control process where a software troubleshoots all functions of the mower.\textsuperscript{2,12} The mowers are not test ran in an open environment. Out of the finished products, samples are picked for extended quality control. The sample is thoroughly examined to determine whether it has been assembled correctly and that it fulfills all specifications.\textsuperscript{12} Quality assurance currently has no excess capacity.\textsuperscript{2}

### 4.6. Remanufacturing

Production strategy for the robotic lawn mowers is at this time linear, the sustainability of the product only being promoted through maintenance, service and seasonal storage.\textsuperscript{5} To restore a mower which is younger than ten years to a resale condition, some simple refurbishing steps could be applied, such as cleaning and replacing some parts; e.g. body and driving wheels. More expensive components, such as the circuit board, are not usually repaired but instead they are replaced.\textsuperscript{9}

#### 4.6.1. Return of Cores

Due to the battery component of the machine, Husqvarna and in turn their customers have a responsibility to dispose of the product in a correct manner. The mower should be returned to the dealer, so that they can disassemble the unit and sort or dispose of the parts.\textsuperscript{10} The dealers rarely receive old robots, but when they do the product gets disposed of at no additional cost for the customer.\textsuperscript{19} Probable causes for the number of returned products being low is that the end customers either keep their old mowers and store them, give them away or that they dispose of them themselves.\textsuperscript{10,19} However, the return of old mowers to dealers seems to be increasing over time, and this should be reasonable since Husqvarna have increased their sales of new products.\textsuperscript{15,16}

The majority of returned products are received when a customer upgrades from one lawn mower to a newer version, often when the previous lawn mower is at the end of its lifetime and in need of expensive repairs to continue functioning,\textsuperscript{8,10,20,21,22} and a comparably small amount of cash is then offered to the customer for the old unit.\textsuperscript{8,10,20} Some of the parts are then cannibalized to be used as spare parts, while other are recycled.\textsuperscript{19,20} There are in general no further incentives set for the end
customer to return their used machines, but a Husqvarna Controller thought that Husqvarna should be able to pay for cores, the only question being how much. However, there are dealers currently, who actively tries to retrieve cores by providing the customer with incentives or a discount on a new lawn mower. One such promotion produced a return rate of approximately 25 percent of the targeted models.

As stated previously above, most of the old lawn mowers do not reach the dealers, and the dealers most often have no clue what the end customers do with them. Only guessing that these machines are given away, used at a different location like a summer home or kept in the garage etc. One dealer mentioned that approximately 30 percent of their old lawn mowers are returned when their customers buy a new product. The dealers would probably receive more cores, and in better conditions, if there was an incentive for the customer to return an old product, and they would gladly help Husqvarna with the collection process if they could benefit from it financially. Currently, Husqvarna’s transports for their main distribution centers are effectively only one-way, but the transportation process could be altered to include return of cores.

4.6.2. Remanufacturing Speculation

For the remanufacturing process to work the interviewed R&D manager and Strategy Director thought that all the components have to be diagnosed to determine the condition of them to make sure that the mower has the quality that the customers expect after the process. Such quality assurance competence currently only exists at the factories and needs to be further built upon to be able to manage the more detailed inspections and testing required for remanufacturing. However, the factories do not have free capacity available, and the remanufacturing process would require its separate line.

For possible implementation of a remanufacturing process, the interviewed Lean Manager and Logistics Director recommend the warehouses as they already have spare parts easily accessible, only extra expertise and transportation being required. The workers at these warehouses do not have the required expertise for a remanufacturing process, since they do not possess any sizeable knowledge about the product and components they are handling. No additional machinery is required for establishing a remanufacturing process. With the correct tools and service education the task could feasibly be conducted manually, and should not require a line flow. However, some reprogramming of the robotic lawn mower could also be necessary.

The interviewed Product Manager thought that Husqvarna should be able to increase the pressure on dealers, so that their services and potential remanufacturing processes would be more standardized with high quality. Not all dealers will be able to achieve this, but it should be possible to focus on a few which have the capacity. It is also possible to make classes among the dealers, where only some can perform a remanufacturing process if they fulfill a set of requirements. The remanufacturing process should be able to be performed during the winter time in parallel with the regular service and storage, when the lawn mower is not used, or during any parts of the off-season. If necessary, the service checklist can be extended and made more detailed to act as a remanufacturing checklist.

The dealers can determine their own sale prices for the mowers they buy from Husqvarna for a predetermined set price. Husqvarna do not receive additional income if a dealer chooses to sell the mower for more than what Husqvarna recommends. For remanufacturing to be interesting for the
dealers, one dealer\textsuperscript{20} thought that similar profit margins between the original and remanufactured products are necessary, while the price of the remanufactured product should also be lower for the end customer. Remanufacturing at the dealers could be beneficial for Husqvarna by ensuring their dealers are profitable, as they rely on their dealers for almost all sales and in turn their profits.\textsuperscript{18} Also, the more dealers there are, the more end customers Husqvarna potentially could reach with their products.\textsuperscript{2} If the dealers are performing a potential remanufacturing process while considering the current relationship between them and Husqvarna, Husqvarna would only be able to gain monetary worth from the process by the additional sales of spare parts, similar to how Husqvarna do not receive a portion of the dealers’ sales profits.\textsuperscript{9}

The interviewed Logistics Director\textsuperscript{4} thought that Husqvarna do not have the knowledge or capability to perform remanufacturing by themselves, and that another party instead should have that responsibility, as did the Commercial Rental Entrepreneur.\textsuperscript{21} A department Vice President\textsuperscript{1} proposed a third-party alternative for the remanufacturing process in their interview, where neither Husqvarna or their dealers perform the remanufacturing process. They thought that the remanufacturing process would be complex and would require a scale that the dealers are not capable of handling. While Husqvarna are good at delivering technical solutions, there are other companies which are better at logistics, transactions, discounts and many other factors required to sell a product efficiently, therefore a third-party company who has these skillsets should be suitable for remanufacturing. Remanufactured products could also be part of a leasing contract, where the customer returns the product after three years of use.\textsuperscript{4} However, the interviewed Project Manager\textsuperscript{15} and Spare Parts Specialist\textsuperscript{16} believed that allowing a third-party (non-dealer) remanufacturer could damage the relationship between Husqvarna and their dealers, as the dealers will be dissatisfied if their sales and service volumes decrease. This is partly confirmed by the dealers\textsuperscript{21,22} who stated that they would much rather perform the remanufacturing process themselves as long as they have capacity for it, than to provide cores for other parties.

4.6.3. Other Sustainable Solutions
In subsection 4.6.1 it was previously mentioned that there are dealers who have during the previous service seasons performed restoration of cores. In one such case, offers were sent to customers who had handed in a robotic lawn mower of model 220 for service and winter storage, where the customer could opt to buy a new model at a reduced price if they let the dealer keep their old machine. It was also made clear that the old robot would either be recycled or used by another customer in the future.\textsuperscript{21}

Collected cores were serviced according to the usual service protocol, if the robot was not too expensive to fix. Time, tools and costs were therefore pretty much the same as for a normal service procedure. Restored units were then sold through the dealers’ normal sales channels. According to the dealer themselves the whole project was a moderate success.\textsuperscript{21}

A concept called Husqvarna Care is in development to explore the prospects of new business approaches such as business to customer leasing for the company.\textsuperscript{1,14} The Husqvarna Care concept plans to offer after-sales solutions for their customers. It will mainly be split into two fields; one for private customers and one for professional. The concept is planned to consist of a few different stages of offerings ranging from leasing the product to a complete carefree ownership where everything needed to run the product is taken care of by Husqvarna while the customer pays a monthly fee.\textsuperscript{14} It is expected that private customers would want new products in their offerings while the professional
customers would accept used products to a larger extent as long as it is guaranteed that the product will work.\textsuperscript{14,23} This principle can be utilized by restoring the condition of a returned working core and reintroducing it to the Husqvarna Care program for a suitable customer segment.\textsuperscript{14}

4.7. Investments

Financial investments at Husqvarna are evaluated through cash flow and net present value analysis, weighing the results of not moving forward with an investment against doing just so. Payoff or payback methods are also utilized to bring depth when presenting investment options.\textsuperscript{3} The calculations are based upon an established framework.\textsuperscript{17} A starting point in investment calculations is the $w_{acc}$ value (weighted average cost of capital) which is presented by Husqvarna Group as individual values for each country the company is active in.\textsuperscript{3}

4.8. Current Market

The products are currently sold mainly by dealers\textsuperscript{5,18} or through online sales channels.\textsuperscript{6} There currently exists little to no second-hand market of the robotic lawn mowers\textsuperscript{10}, some believing there currently exists potential customers that would be interested in remanufactured products\textsuperscript{18,20}, while others do not due to the relatively low effective price of a mower.\textsuperscript{10} However, there are dealers who currently sell used lawn mowers with ease along with installation kits, warranty and service offerings.\textsuperscript{18,21,22}

Owners of the robotic lawn mowers usually do not want to go back to using a manually operated lawn mower. They see two main benefits of using a robotic lawn mower; they are less noisy, and they require less active work. The robots also act as social status symbols.\textsuperscript{10} Most customers use their mower for the entirety of its lifetime, but there is also a segment of forerunners that constantly update themselves to the current generation of mowers.\textsuperscript{18,19}

The dealers are in general content with the current sales situation, expressing that they would rather sell new products instead of used.\textsuperscript{10} The interviewed Product Manager\textsuperscript{8} had also spoken to some dealers who did not think their private customers would want a leasing service. There exist, however, leasing to commercial customers with a leasing period of a few years, where a leasing agreement has similar contents to a normal full service agreement (see section 4.4) apart from the fact that the robotic lawn mower itself is never owned by the commercial client.\textsuperscript{1,23} For private customers there is a company which provide customers with lawn mowers in a subscription service\textsuperscript{1}. There are also small leasing projects performed by dealers.\textsuperscript{21} This is the closest to private leasing there is for this product.\textsuperscript{11}

4.9. Future Market

Managers at Husqvarna\textsuperscript{17,9} thinks that it is important to offer remanufacturing in the future. It is good that the company takes responsibility for its products, as reuse and environmental awareness are in fashion,\textsuperscript{3} which further can be used as marketing aspects.\textsuperscript{9} It also can be useful to utilize the concept to reach markets that are not mature yet. The step to buy a robotic lawn mower can be too big for some, since the product is quite expensive. The interviewed R&D Manager\textsuperscript{9} thought that a remanufactured product could be sold with the current Husqvarna brand, while some\textsuperscript{19,20,23} thought a lower price tag would remove the premium perception of the brand, depending on how large the reduction in price would be as customers often link price to quality.\textsuperscript{20} Other dealers\textsuperscript{21,22} thought old or remanufactured lawn mowers would not affect the perception of the brand, since only customers that cannot afford a new one would buy them or the product would be perceived to be of high quality if it could be resold. It is also believed that remanufactured products would increase the differentiation
of the product portfolio which should enable Husqvarna to compete against cheaper products.\textsuperscript{2,3,23} Moreover, the interviewed Controller\textsuperscript{17} thought that it was important for Husqvarna to take steps towards remanufacturing immediately before someone else take the opportunity to perform it in a larger scale, as there are small private actors on the market who restore the condition of lawn mowers already.

The market is constantly changing, and by year 2025 the interviewed Sustainability Manager\textsuperscript{6} believed that Husqvarna will sell more through their online sales channels. They also mentioned that changing the customer behavior from a “buy new product” mindset to “buy remanufactured” takes time. Eventually, this could lead to dealers roles changing from mainly selling lawn mowers to only providing service, repair or remanufacture to the products sold by Husqvarna.\textsuperscript{6} It is therefore important to focus on small segments of the market first, where remanufacturing could be successfully introduced.\textsuperscript{6,8} By the same year the interviewed Vice President\textsuperscript{1} thought that more customers will lease or utilize other similar systems to get a product which the customers do not have to maintain themselves.
5. Analysis of Remanufacturing Alternatives

This chapter presents connections between important steps in a remanufacturing process to the current state of Husqvarna. Alternatives for the process and their prerequisites for it are defined and evaluated through SWOT-analysis. The most prominent alternatives are selected for NPV-analysis in the following chapter.

5.1. First Steps for Remanufacturing

As discussed in section 3.1, the first step in shifting your business towards remanufacturing and a circular economic strategy is to enforce the circular mindset throughout the organization by integrating or connecting it to the company vision. As Husqvarna’s own focus in their company vision lies with ‘leadership in sustainable, user-centered solutions’ (Husqvarna Group, 2018b), a connection can already easily be made. Communicating the upcoming change in relation to a clear vision will ease the imminent transitions necessary when adjusting the business models and designs (Bocken, et al., 2016). Husqvarna also need to select the foundation on which they will base their strategy (Fischer & Achterberg, 2016). Optimal use is the current sustainable foundation, it has long been a consideration and the products therefore have regular service available, and now Husqvarna wants to increase their circularity by adding on to their foundation with value recovery through remanufacturing.

5.2. Core Acquisition

The alternatives to acquire cores must be identified to be able to gather cores for the remanufacturing process. In subsection 3.2.4 seven different parts of acquisition management were listed, however, since Husqvarna have not performed any form of remanufacturing previously the most important parts are the return strategies. As previously mentioned by Ayres et al. (1997) and Guide Jr & Van Wassenhove (2001) return strategies are a fundamental requirement for the successfulness of a remanufacturing process, since it will not be possible if the return flow is non-existent. The closed-loop supply chain relationships which Östlin et al. (2008a) list (Table 2) were determined to be used to investigate how the robotic lawn mowers could be gathered.

Husqvarna themselves did not have a direct communication channel with their customers outside of their concept store, since most of the sales were made through their dealers. They did not have any returns of cores either, except for products returned to said concept store. Some of Husqvarna’s dealers occasionally received cores from their customers when they bought new products, but the quality of these varied in the lower end of the spectrum since most were in poor condition when the customer decided that a new product had to be purchased. This meant that there must be some kind of incentive for the customers to return the product in a condition and quantity which allows remanufacturing to be feasible.

Without changing Husqvarna’s current business model towards private customers, where they sell most of their lawn mowers through their dealers, five of the seven closed-loop supply chain relationships were identified as appropriate (ownership-based and service-contract were excluded due to the alternate contract regulated business models necessary for these relationships). This was reduced to four, as one of these was voluntary-based, where the core is returned for free (Östlin, et al., 2008a). This was in use by Husqvarna, but as previously mentioned, it did not provide the system with high quality cores in reasonable volumes. The remaining four are direct order, deposit order, credit based and buy back. These are similar in terms of that the customer retrieves cash, credit or an opportunity to acquire a discounted remanufactured product when returning a core.
Since these relationships can be simultaneously used as complements (Östlin, et al., 2008a) as mixed return strategies (Wei, et al., 2015), and because they are quite similar, the cost for implementing and using these should be nearly equal. They do, however, have advantages and disadvantages as listed in Table 2, which should be considered for the real implementation process. For the time being, when remanufacturing is relatively unknown it could be beneficial to focus on direct-order together with credit-based or buy-back, since this would either allow a customer to hand in their product and get it remanufactured in a similar manner as the current service offer or get a monetary value when returning their old product to buy a new one. This would either supply the remanufacturing process with cores or provide an option for the customer to keep their old product which could have sentimental value or to prevent negative attributes such as disgust when buying another used product (Abbey, et al., 2015a; Abbey, et al., 2015b).

If Husqvarna instead would want to change their business model by offering their lawn mowers as PSS or leasing to private customer, which they already have started to introduce to professional customers and experiment with, there were two relationships that could be used; ownership-based and service-contract. This approach could also provide additional synergy effects in combination with remanufacturing (Kurilova-Palisaitiene, et al., 2018), and be a good way of introducing remanufacturing to a company’s systems (Yang, et al., 2018). The main difference between ownership- and service-contract relationship was that for the latter relationship the customer owns the product when the remanufacturing process is contracted as part of a service. Using these methods would satisfy Husqvarna’s demand of cores as they would know when the product is returned in ownership-based or by specifying when the product should be returned in the service contract. This assumption is confirmed by the research of Sundin & Bras (2005). Moreover, this approach gave Husqvarna three options; performing the whole remanufacturing process by themselves, by contracting dealers or by contracting a third party. However, one should remember that customers tend to use leased or rented products more carelessly which increases wear and in turn remanufacturing costs (Kuo, 2011), even though in the case of autonomous products this risk should not be as prevalent.

The actual core gathering process, which is part of the reverse channel (Wei, et al., 2015), should only depend on if the remanufacturing process is performed in a centralized location or decentralized locations, once the closed-loop supply chain relationship has been determined. In the centralized case, Husqvarna could either establish a direct channel of communication to their end-customers or contract the dealers to gather the cores for them, by acting as collection centers (Melo, et al., 2009). In the decentralized case, the dealers would have the main responsibility for the remanufacturing process (Savaskan, et al., 2004), and therefore they would also gather the cores directly from the end-customers. But not all dealers would have the capacity for remanufacturing, even in a smaller scale. However, these dealers should be able to help with the gathering process for the dealers who then would perform remanufacturing.

One could however argue that it would be more likely that the collected quantity of cores for remanufacturing would be higher in the decentralized alternative than for a centralized alternative. Some dealers already perform a process similar to remanufacturing and may hesitate to provide Husqvarna with additional cores, and other dealers may perceive the sales of remanufactured products as a competitor to their own business as discussed in subsection 4.6.2. Even if the remanufactured lawn mowers would be sold by the dealers, a too low profit margin on such products could deter the
dealers from encouraging and helping a remanufacturing process, to be able to continue selling newly manufactured products. This last scenario would not be too probable due to market segmentation between new and remanufactured consumer products (Guide Jr & Li, 2010), but in this case, it is the dealer’s perception of the matter that would influence the core acquisition and sales opportunities.

5.3. Inspection Process

Where the inspection process would be performed affects the first steps of the remanufacturing supply chain. Thierry et al. (1995) stated that quality classification is important, since most cores will have defects and faults which will affect the remanufacturing process. This would also affect the value of the incentive if it is based on the value of the core (Wei, et al., 2015), which was previously covered in section 5.2. The end-customer themselves should be able to conduct a visual examination of the core and provide this information to the remanufacturer. The information would however likely not be accurate and detailed enough to fully determine the true condition of the core.

The inspection process must be performed either at the core gathering site, directly at the remanufacturer or at an intermediate location in the logistics chain, such as a distribution center, to achieve a standardized process where all cores are examined equally, since a consistent process is important to assure similar and accurate pricing on the cores. What would be most appropriate should depend mostly on the cases of a centralized or decentralized approach. If the dealers are responsible for a remanufacturing process, it seems reasonable that they also should take responsibility for the inspection and quality classification process. But if Husqvarna perform the remanufacturing in a centralized way, then the product could be inspected at the remanufacturing location, at another location in the logistics chain or at the dealers if they are part of the process. Inspection at the remanufacturing plant would be an assessment process with low variety in determining the actual quality and value for incentive of the core. This would apply for the inspection at another location in the logistics chain as well if it consisted of a single location with equal resources. By using a direct channel to gather cores from end-customers, this process could be relatively quick, while using dealers for gathering as a middle hand would probably slow down the process leaving the end-customer waiting for the inspection. The latter means that the customer would have to wait for the inspection process if the incentive value is based on the quality of the core. The slowed down process would be a consequence of having more steps in the process which results in additional transportation and waiting times.

One solution for the case when the end-customer has to wait a period of time would be to determine a standard incentive for any returned cores, which the customer would retrieve immediately. Then after the inspection process, if the core is in a good condition the customer would be given the remaining incentive. This approach would hopefully satisfy the customers, who would have to wait for an extended period of time. In addition to the waiting time, this could result in unnecessary transportation costs as it is not known beforehand if the core could be remanufactured. An inspection process at the dealers before remanufacturing at a centralized location may also have issues with the assessment, since it would be difficult to determine the quality of the core exactly the same across multiple sites. This problem was visible when comparing the service procedure of the dealers which varied in quality and costs.

If the inspection and the remanufacturing process would be split between different parties, it might result in additional cost. There are at least two reasons for this. The first reason is that the dealers
would not inspect for free. The second is that the lawn mower must be disassembled to be inspected, then packed into a parcel and sent to the remanufacturer. The lawn mower could either be packed in the disassembled state or reassembled and then packed. Reassembling would consume time, hence also increasing the total cost. It might also be difficult to ensure that no parts are damaged during the delivery if the product is packed in a disassembled state, and the remanufacturing time might increase if the remanufacturer must identify and sort the components. faulty inspection and quality assessment could affect the remanufacturer negatively resulting in e.g. replacing high quality parts or leaving worn parts in the product. To prevent this the remanufacturer might need an additional inspection process, which could increase the costs further.

5.4. Production Systems for Remanufacturing

Lund (1984) stated that remanufacturing is performed through an industrial process, and that the quality and performance of the product must at least meet the condition of a new product. Part of a manufacturing strategy is to determine the highest priority output, and deciding which trade-offs that must be made (Boyer & Lewis, 2002; Garvin, 1987; Miltenburg, 2008; Skinner, 1974; Wheelwright, 1984), which is a necessary prioritization to reach the fullest potential of a production system (Hill, 1983; 2000). From the interview study it was identified that the most important manufacturing output for Husqvarna is quality, therefore it was used as a basis for the production system analysis.

Out of the production systems presented by Miltenburg (2005) continuous flow has the highest capability to provide high quality (Figure 4), however its flexibility is very low. A production system for a remanufacturing process must have a reasonably high flexibility to handle different models and conditions of cores, since each core would not require the same restoration process. This made the continuous flow system not suitable for remanufacturing, as it is specialized in producing standardized products with little variations (Lee, 1992; Miltenburg, 2005), which is the opposite of what Seitz & Peattie (2004) state is required for a remanufacturing process.

The equipment-pace line flow system has the second highest quality output of the production systems, but just like continuous flow it has low flexibility (Miltenburg, 2005). However, as stated by Hill (2000) and Miltenburg (2005) it should be able to handle a few different products, which could be enough for the lawn mowers if inspection and preparation of the cores is thoroughly performed before they are put into the process. Even though Husqvarna are introducing more automation to their current production system, it is mostly not automated. This means that the know-how of setting up and running an automated production system is missing at Husqvarna and introducing automation for remanufacturing before manufacturing could therefore be a significant risk-taking in terms of inability to adapt to product variants. However, if implemented successfully the cost and the lead time of the remanufacturing process would be low, which would be beneficial for Husqvarna’s competitiveness.

Two of the production systems, FMS and JIT, are positioned off the diagonal (Figure 5) which results in complex production systems (Haley & Goldberg, 1995), but they could also reach combinations of manufacturing outputs other production systems cannot, as seen in Figure 4. All of the manufacturing outputs for JIT are high, which makes this production system seem like the best option in most cases, but as Miltenburg (2005) stressed it is difficult to achieve the highest outputs of the system due to its high complexity. The system also requires deliveries of cores just in time, which is difficult for a remanufacturing system to achieve, as the uncertainty of the arrival of cores is usually high (Kurilova-Palisaitiene, et al., 2018) and due to the overall complexity and uncertainty of a remanufacturing
process (Lundmark, et al., 2009). Therefore, the complex production system JIT is probably not the most appropriate system for a complex and uncertain process like remanufacturing, despite its high outputs.

The production system FMS on the other hand has the capability to provide high flexibility outputs whilst not having as tough requirements as JIT, which makes it appropriate to handle the uncertainty of a remanufacturing process. But as stated previously, the FMS is a complex system, and could therefore be difficult to master. Just like the EPL system FMS is based on automatization (Chan, et al., 2002), which is something Husqvarna currently are not experienced in. This is one reason that FMS might not be the best option for Husqvarna, but for a company with experience in automatization it could be suitable, since it has the capability to handle many product varieties in low volume batches while providing most manufacturing outputs at high levels (Miltenburg, 2005).

For the three remaining production systems (job shop, batch flow and operator-paced flow line) the quality output is in the lower half of the spectrum, but flexibility is high for all of them (Miltenburg, 2005). However, a downside beyond the quality with these systems is that the production costs begin to rise, which could be an obstacle preventing a profitable remanufacturing process, since the profit margin of remanufactured products can be low (Dowlatshahi, 2005; Sundin, et al., 2016). But the high flexibility of these allow for a remanufacturing process capable of handling low to medium volumes and cores of different models and conditions, which would be needed to handle the uncertainty of core condition and arrival rate.

Husqvarna’s production of new lawn mowers is a batch-wise line flow with a few automated steps. From the interview study their system was concluded to be of a type similar to an OPL system. Therefore, Husqvarna has experience on how such a system works, which could aid the implementation of a similar system for remanufacturing. Job shop and batch flow are simple production systems, which should be easy to implement as well, but their quality outputs are even lower than that of an OPL system (Miltenburg, 2005). The quality of the end product could still be equal to the quality of a new product from these systems if a structured and detailed workflow, as well as an extended quality assurance process are implemented. Resulting consequences might be increased costs, due to a significant number of products that are returned to the production system after failing the quality assessment. Except from the potential low quality, these production systems are suitable for a remanufacturing process of low to medium volumes thanks to their high flexibilities.

The only production systems that have been identified to not suit remanufacturing in this case were continuous flow and just-in-time due to low flexibility and uncertainty, while the others should be appropriate as long as their individual strengths and weaknesses in terms of volume, variety and quality are considered in the implementation process. However, complex production systems such as EPL and FMS could be difficult to implement appropriately but should be feasible if enough resources are invested in the best possible equipment and if enough knowledge of the behavior of the remanufactured product is gathered beforehand. How each of the production systems were suitable for a general remanufacturing system and Husqvarna’s current supply chain specifically is summarized in Table 4 below, while the different alternatives for Husqvarna’s approaches to remanufacturing are covered further in section 5.5.
Table 4 - Suitability of the production systems for remanufacturing.

<table>
<thead>
<tr>
<th>Method</th>
<th>Suitable for remanufacturing</th>
<th>View from Husqvarna's supply chain</th>
<th>Volume (Miltenburg, 2005)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Job Shop</td>
<td>Yes</td>
<td>Yes</td>
<td>Very Low</td>
</tr>
<tr>
<td>Batch Flow</td>
<td>Yes</td>
<td>Yes</td>
<td>Low</td>
</tr>
<tr>
<td>OPL</td>
<td>Yes</td>
<td>Yes</td>
<td>Medium</td>
</tr>
<tr>
<td>FMS</td>
<td>Yes</td>
<td>Risky, as it is difficult to master and requires additional automatization.</td>
<td>Low</td>
</tr>
<tr>
<td>JIT</td>
<td>No, high uncertainty will cause issues.</td>
<td>No</td>
<td>Low to Medium</td>
</tr>
<tr>
<td>EPL</td>
<td>Yes</td>
<td>Risky, as it has low flexibility and requires additional automatization.</td>
<td>High</td>
</tr>
<tr>
<td>CF</td>
<td>No, low capability for variety.</td>
<td>No</td>
<td>Very High</td>
</tr>
</tbody>
</table>

5.5. SWOT Analysis of Alternatives

Based on the current state and the different approaches of core acquisition and inspection previously stated above, multiple approaches for remanufacturing could be analyzed. Three main types of remanufacturing alternatives were identified for Husqvarna; the centralized, decentralized and combined approaches. These alternatives have different advantages and disadvantages which will be further analyzed in the following sections, outlining the prerequisites of each location for a standalone remanufacturing process.

The main difference between these types of alternatives was who would be responsible for the remanufacturing process; Husqvarna, a third party, or the dealers. Moreover, the centralized case could be split further to allow for location selection within the spare part warehouse, the international manufacturing plants, a new location, or the use of a third-party remanufacturer.

For each alternative the remanufacturing procedure was investigated, which included the following five steps (note that the order is not fixed):

1. Core arrives through a logistics channel
2. Core is inspected and moved to remanufacturing
3. Required parts are retrieved
4. The core is remanufactured
5. The product is reintroduced to the market

As handled in section 5.2, there were two paths for how Husqvarna could approach the market of remanufacturing. This would be either by selling the robotic lawn mowers as a service offer which included remanufacturing or by traditional sales with an incentive for core returns. To refer to these two approaches the terms core service and core incentive has been utilized. If neither of these are mentioned
when core gathering is stated in the following subsection, it is assumed that either of them can be used without issues.

5.5.1. Centralized

In the centralized case Husqvarna or a third party would perform the remanufacturing process, but core gathering and inspection might be handled by either one of them or the dealers. How the remanufactured robotic lawn mower would be reintroduced to the market must also be covered. A remanufactured product in a centralized environment could either be sold directly to the end-customer or through the dealers. Any direct channel has not been widely used by Husqvarna, but it could allow a better price for the customer compared to the other alternative, since the dealers would demand profitability as well. However, a common issue with remanufactured products is that the profit margin is low (Dowlatshahi, 2005; Sundin, et al., 2016), which is also affected by the reputation of the seller and the provided warranty offers when purchasing remanufactured products (Subramanian & Subramanyam, 2012).

Furthermore, some managers from Husqvarna believed that the sales from Husqvarna’s online channels will increase in the future, which could be utilized when introducing remanufactured products to the market. Husqvarna have never had remanufactured lawn mowers, therefore the market can been seen as immature which could result in low sales volumes (Lundmark, et al., 2009). Further expanding the online sales channel and selling remanufactured products could benefit the channel itself and the product, as early adaptors and environmental conscious customers from new segments could find the product and eventually spread the idea (Gan, et al., 2017).

Spare Parts Warehouse - Torsvik

Out of the centralized alternatives the spare parts warehouse at Torsvik was covered first. The warehouse most often has all the required spare parts available, which mean that the supply of components would not have to be altered for a remanufacturing process to be possible. The reverse supply chain of cores must be introduced for the arrival of cores, but it should not differ much from the current inflow, since the existing infrastructure could be utilized due to close proximity to the warehouse. Fleischmann et al. (2001) and Thierry et al. (1995) state that the reverse flow is often combined with the existing logistics channel, which means that an introduction of a reverse supply chain to the current system should be a suitable and feasible solution. The approaches core service or core incentive should not affect the method considerably, since the cores would arrive to the distribution center nonetheless, only with some differences in quantity and arrival distribution. As briefly covered in section 5.3, if the inspection process is performed centralized separately from the gathering site there is a risk of transporting non-remanufacturable cores, resulting in additional costs. Figure 9 shows the different material flows of this alternative.
A facility at the spare part warehouse or an area within would be required for the remanufacturing process. However, performing remanufacturing in the warehouse facilities would not be possible due to two reasons: at the time of the analysis there is no free capacity, and the warehouse is run by a third party. This means that the only option would be to select a location nearby. Since no production or service was performed in the proximity of the warehouse all the necessary equipment for the remanufacturing process must be purchased. The workforce must be relocated from elsewhere or hired. To ensure that the quality of the remanufacturing process is high from the beginning, operators and managers with high experience in the current service and manufacturing processes would be required. This competence would only have to be built from scratch once, since there is only one larger spare part warehouse in Sweden. Husqvarna’s main hub are nearby which could also ensure that the competence level of the remanufacturing facility is kept high.

Husqvarna is a large company, and therefore they should be able to invest in the best possible equipment for a remanufacturing process. The initial investment for this alternative would probably be big, since a new facility must be acquired or rented in addition to all the equipment in need of purchase. Having a main center for remanufacturing would mean that cores are aggregated into one location resulting in relatively high volumes, which allows for more expensive equipment and even automatization to some degrees. The production system could follow a line flow such as OPL or EPL which would provide low costs, while keeping the quality high (Miltenburg, 2005). The choice of production system would depend on the expected volume of the acquired cores and whether Husqvarna would want to apply a more risk-taking procedure by implementing an EPL system.

Using the existent networks and resources available greatly benefits a remanufacturing system (Dowlatshahi, 2005). Therefore, once the lawn mower has been remanufactured, the warehouse should be able to utilize the nearby logistics solution to redistribute the product to the market, either through a new online channel or the dealers to minimize the need for additional investments in terms of new logistics solutions.

Prerequisites for implementing a remanufacturing process at this location in terms of operational, logistics, and labor factors are presented in Table 5. These and additional factors have from the above reasoning and information from the current state been slotted into Figure 10 to create an overview of the total capabilities of this alternative.
Table 5 - Existent prerequisites for the centralized alternative “Spare Parts Warehouse – Torsvik”.

<table>
<thead>
<tr>
<th>Operational Factors</th>
<th>Logistics Factors</th>
<th>Labor Factors</th>
</tr>
</thead>
<tbody>
<tr>
<td>- Facilities made for the purpose at hand</td>
<td>- Logistics network available</td>
<td>- Must build up the competency</td>
</tr>
<tr>
<td>- Economies of scale production</td>
<td>- Spare parts readily available</td>
<td>- Located near the main hub with varying competences</td>
</tr>
<tr>
<td>- Standardized process and consistent quality</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Figure 10 - SWOT figure for the centralized alternative “Spare Parts Warehouse – Torsvik”.

International Manufacturing Plants

The international manufacturing plants have most of the necessary components already at site just like the warehouse, which could provide easy access to parts for the remanufacturing process and promote effective resource utilization. The reverse logistics channel must be developed to allow for the return of cores, and the storage area must have room to store them. To prevent that the reverse logistics channel would be too expensive, the existing distribution centers might have to be part of the process, by batching the cores from each market making them ready for transportation. This would also add stress to the distribution centers in term of higher throughput and required storage capacity.

No changes to the original logistics channel should however be necessary for distribution of the remanufactured products, since they should be able to use the same transport solutions as the new products. Figure 11 shows the different material flows of this alternative.
It also was identified that the manufacturing plants did not have free capacity available, and that the cores would probably not be able to utilize the existing lines. This meant that either changes to the number of lines or the layout of the plants must be introduced to make space for remanufacturing, or a new facility must be built or acquired in the proximity of the plants. Changing the existing layout and manufacturing process could be costly and even disturb the production of new products. The operators and managers from the current production had the competence to understand the principles of the service and the remanufacturing process, but to be able to inspect and assess the quality of the cores, some additional education might be required. The location ensures that a high competency level near the remanufacturing process would be available at all times and being able to use this knowledge in setting up the remanufacturing process would improve its chances of being effective (Dowlatshahi, 2005).

Since the manufacturing plants were located in the United Kingdom and the Czech Republic most cores needed to be transported across national borders to reach either of the plants, which could be costly, especially if tariffs must be paid. The transportation would also take time, which increases the duration a customer would have to wait for the product if a direct-order closed-loop supply chain relationship were used or if a customer had to wait for the inspection process at the plant to receive their incentive. The long transport would also further negatively affect the profitability when a core of low quality would be received which could not be remanufactured, as transportation costs still would apply but no profit could be made. Therefore, inspection directly at the core gathering site might be the better for this alternative, which also is a requirement for a core incentive approach as various currencies and laws of different countries would otherwise add complexity to the process.

The remanufacturing process at these two locations would also require higher capacity than the spare parts warehouses since the plants are fewer and would cover larger markets. As previously stated, a remanufacturing process at the manufacturing plants might require a capacity increase to handle relatively high volumes. This provides an opportunity to cut remanufacturing costs if a complex production system such as EPL or FMS is chosen. The initial cost follows the same analogy as for the spare part warehouse, where a large initial investment may be required to set up all the required equipment for the process.

Prerequisites for implementing a remanufacturing process at this location in terms of operational, logistics, and labor factors are presented in Table 6. These and additional factors have from the above reasoning and information from the current state been slotted into Figure 12 to create an overview of the total capabilities of this alternative.
Table 6 - Existent prerequisites for the centralized alternative “International Manufacturing Plants”.

<table>
<thead>
<tr>
<th>Operational Factors</th>
<th>Logistics Factors</th>
<th>Labor Factors</th>
</tr>
</thead>
<tbody>
<tr>
<td>- Greater economies of scale production</td>
<td>- Logistics network available</td>
<td>- Competences in production and quality</td>
</tr>
<tr>
<td>- Standardized process and consistent quality</td>
<td>- Spare parts close</td>
<td></td>
</tr>
<tr>
<td>- Remanufacture may interfere with normal activities</td>
<td>- Long and expensive transports</td>
<td></td>
</tr>
</tbody>
</table>

**Figure 12 - SWOT figure for the centralized alternative “International Manufacturing Plants”**

**New Location**

A new location for a centralized remanufacturing process would also be possible. In subsection 3.2.5 different approaches to analyze a location were presented, where the most common approaches were optimization models based on cost (Chen, et al., 2014; Cheng, et al., 2015), but other factors might have a bigger impact in terms of tangible and intangible factors (Cheng, et al., 2015; Schmenner, 1979), which range from performance of the supply chain (Bhatnagar & Sohal, 2005; Dowlatshahi, 2005; MacCormack, et al., 1994), proximity to market (Cheng, et al., 2015) to social (Terouhid, et al., 2012) and logistics factors (Lu, et al., 2014). Therefore, a potential new location will be based on general factors which would affect the successfulness of remanufacturing.

A new location would have the possibility for Husqvarna to develop a production system which outputs their highest priority, quality, with an acceptable delivery time and cost to ensure that the Husqvarna brand keeps its reputation, remain profitable and keep the customers satisfied. If the remanufacturing volumes would be expected to be high, and if Husqvarna wanted to develop methods
to disassemble and reassemble the robotic lawn mower with an automated process, then an EPL or FMS production system could be possible. However, an EPL system would provide low flexibility (Miltenburg, 2008), which is not beneficial for cores with many variations, therefore FMS would be more suitable if the volumes are not high. Even less automation sets an OPL system as an appropriate choice by providing good quality, good flexibility and reasonable delivery and cost outputs.

When an appropriate production system has been identified, a location in general supply chain terms must be selected. The possible production systems require a large facility, especially if the expected remanufactured volume would be large. This requires a high initial investment as the new facility would have to be purchased or built unless rented, and then a new logistics system must be implemented which further increases the complexity and cost of the investment. The question is then, where should the remanufacturing center be located? When combining the results of the studies by Jakubicek & Woudsma (2011) and Karakaya & Canel (1998) factors such as availability of skilled workers, cost of land and facilities, tax rates and access to major customers were seen as important when considering a potential location. Therefore, these were taken into account when determining the possible location of the remanufacturing center.

The position of the new location should be near the market, that is, near the customers so that the transportation costs to and from the facility are kept to a minimum. The cost of establishing in the area and running the operations must also be low. However, the current distribution centers and spare parts warehouses are located with this in mind already, which prevents the new location to be at the center of the market, since otherwise the new location would be the same as that of the main distribution center. The tax rates would not affect the choice, if the location was limited to be within Sweden, where the corporate tax is independent of the location.

Its location could be in proximity of the biggest customer cluster, which then at least lowers the transportation cost and time for some customers. A new location, which is not near the main warehouse, the manufacturing plants or the main hub would not have available labor with high level of experience nor easy access to spare parts. This would put further stress on the facility, as it must act as a storage of spare parts as well as to be able to provide the remanufacturing process with components. It must also build up the expertise within the work force to be able to achieve high quality remanufactured products. Figure 13 shows the different material flows of this alternative.

![Diagram of Material Flows for the Centralized Alternative "New Location"](image)

The new location approach could result in a significant risk-taking, since the initial investment could be big and irreversible. Another risk would also be the uncertainty regarding the expected quantity of cores which the production system must be scaled to, for it to provide high levels of the manufacturing
outputs. The reason for this is that a production system does only provide economies of scale if the produced volume is appropriate for the selected system. Lower remanufacturing volumes than expected might therefore make the investment result in a loss. For the remaining inspection and core gathering aspects this alternative has the same analogy as the spare part warehouse alternative.

Prerequisites for implementing a remanufacturing process at this location in terms of operational, logistics, and labor factors are presented in Table 7. These and additional factors have from the above reasoning and information from the current state been slotted into Figure 14 to create an overview of the total capabilities of this alternative.

Table 7 - Existent prerequisites for the centralized alternative “New Location”.

<table>
<thead>
<tr>
<th>Operational Factors</th>
<th>Logistics Factors</th>
<th>Labor Factors</th>
</tr>
</thead>
<tbody>
<tr>
<td>- Facilities made for the purpose at hand</td>
<td>- Needs access to spare parts</td>
<td>- Must build up the competency</td>
</tr>
<tr>
<td>- Economies of scale production</td>
<td>- Logistics channels must be built from scratch</td>
<td></td>
</tr>
<tr>
<td>- Standardized process and consistent quality</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Figure 14 - SWOT figure for the centralized alternative “New Location”.

Third Party

The centralized alternative could also consist of a third party, who would be contracted by Husqvarna to perform remanufacturing. Husqvarna are good at realizing technical solutions and developing products, but they do not have the same experience in creating logistics networks or developing
customer relationships directly. By letting a third party perform remanufacturing, Husqvarna would only have to focus on the production of their new products, where most other things would be the third party’s responsibility, similar to Husqvarna’s current relationship with their dealers and warehouses. This should also not require any initial investments from Husqvarna.

The third party should be able to perform remanufacturing on a larger scale like the other centralized alternatives which would result in a lower production cost if an appropriate production system were to be developed. The whole process would also be conducted in a standardized way, which would ensure that the quality of the remanufactured lawn mowers is consistent and probably high. The chosen production system follows the same analogy as the ‘new location’ alternative where EPL, FMS and OPL are potential production systems. Depending on the location of the third party the transportation costs for spare parts, cores and finished products could be high. The competence of the actual product and how it is constructed must be built up, which could pose uncomfortable issues in advanced solutions and design secrets needed to be taught to the third party.

Figure 15 shows the different material flows of this alternative. To gather cores and sell remanufactured products the third party could either advertise that they are buying cores and selling remanufactured products by themselves or contract the current dealers to gather and sell for them. But a remanufactured product sold by a third party, might not be able to uphold the same price as an OEM seller or an authorized dealer as Subramanian & Subramanyam (2012) state, which could lower the profitability of this alternative if that path would be taken. Advertising and buying cores directly from customers would probably be expensive in larger scales, therefore contracting dealers through Husqvarna by core incentive would be the better alternative. Once the customer base has been built up, or through a service offered by Husqvarna, core service could be introduced as well. However, the third party could perform the remanufacturing as part of leasing or PSS themselves as an independent remanufacturer, which excludes Husqvarna from the business opportunity.

![Figure 15 - Material flows for the centralized alternative “Third Party”](image)

For a third-party remanufactured lawn mower sold at the dealers, it would be important to ensure that the dealers could get a competitive profit margin on the lawn mower, otherwise they would much rather sell a new product or something else completely (as other robotic lawn mower brands). The remanufacturing process could also result in a lower number of lawn mowers that are serviced by the dealers since the third party could perform service as well, thus lowering the overall profitability of
the dealers. This could lead to dealers looking for other business opportunities outside of the Husqvarna brand, reducing the market reach and decreasing potential sales of their lawn mowers.

Husqvarna would with this alternative mainly profit from the process by selling spare parts, but they could also retrieve a portion of the profit from the third party if a verified remanufactured by Husqvarna brand is developed where the third party pays a license fee for each product. However, as bootleg variants of some of Husqvarna’s spare parts exist it could be risky to demand too much from a third-party remanufacturer, since they could choose to stop using Husqvarna’s original parts if they would become able to gather cores independently. This would leave Husqvarna with nothing but a remanufactured product that would have the potential to damage the sale of new products by cannibalization (Lebreton, 2006), where the third party could try to target the current sales market segments and compete with new products directly (Buday, 1989; Copulsky, 1976).

Prerequisites for implementing a remanufacturing process at this location in terms of operational, logistics, and labor factors are presented in Table 8. These and additional factors have from the above reasoning and information from the current state been slotted into Figure 16 to create an overview of the total capabilities of this alternative.

Table 8 - Existent prerequisites for the centralized alternative “Third Party”.

<table>
<thead>
<tr>
<th>Operational Factors</th>
<th>Logistics Factors</th>
<th>Labor Factors</th>
</tr>
</thead>
<tbody>
<tr>
<td>- Economies of scale production</td>
<td></td>
<td>- Utilizes third party which has</td>
</tr>
<tr>
<td>- Standardized process with</td>
<td></td>
<td>experience in areas Husqvarna</td>
</tr>
<tr>
<td>consistent quality</td>
<td></td>
<td>do not</td>
</tr>
<tr>
<td>- Many different steps/actors</td>
<td></td>
<td>- Third party has the potential</td>
</tr>
<tr>
<td>drive up the price</td>
<td></td>
<td>to become too independent</td>
</tr>
</tbody>
</table>
5.5.2. Decentralized

In the decentralized case Husqvarna would not be the active party performing the remanufacturing process. Instead the whole process would be handled by the dealers, who would act as gatherers of cores, inspectors, and remanufacturers. Figure 17 shows the different material flows of this alternative. The remanufactured products would most likely be sold by the dealers directly to the end customers for a discounted price, and core incentive will most likely be used for the collection process. As previously stated in subsection 4.6.2 this arrangement would only mean profitability for Husqvarna through the sales of spare parts. The feasibility for the dealers would depend on their available capacity and what margin they would be able to achieve through the process, bearing in mind that profit margins for remanufactured products often are being notably low (Dowlatshahi, 2005; Sundin, et al., 2016). The capacity and size of the dealer's businesses also limits the scalability of this alternative.

As with any of the alternatives, additional education and more advanced knowledge of the lawn mower would be necessary to be able to properly perform the initial inspection and the control of quality after
the remanufacturing process. In this decentralized case the issue of uniform quality arises – how can Husqvarna ensure that these products would be remanufactured to the same level of quality at all the involved dealers? The interviewed Product Manager (personal communication, February 8, 2019) discussed some possibilities concerning this; increasing pressure on conformity throughout the dealer’s activities with the robotic lawn mowers, only allowing remanufacturing if the dealer satisfies certain requirements, and finally an extended service checklist adapted for the remanufacturing process. A new sub-brand could be applied to the remanufactured products as proof of the standardization, which also would ensure that only Husqvarna’s original spare parts are used in the process. The different degrees of training for the dealers, mentioned in section 4.4, could be expanded with a fourth rank, which would include rights to remanufacture and sell remanufactured products beneath this Husqvarna sub-brand. On the other hand, current service activities differ in both prize and quality. If Husqvarna would let the dealers handle the entire process while only providing support such as educational possibilities, the same could be true for the remanufactured products where the dealer would be the one solely responsible for the resulting quality and what price to charge.

Regardless of the core collection method the number of returned cores was expected to be generally low as the main source would be from upgrades, which was a varying but low amount between different dealers. The dealers that do not have the capacity to set up their own remanufacturing process could however retrieve cores if core incentive was to be utilized and then sell them to the dealers who do perform such a process. Here the issue would be to some extent transport, but mostly the appraisal of cores, as the dealers without the extra knowledge may misevaluate the cores. Therefore, they would run the risk of purchasing and selling cores to other dealers at a loss. Consequently, it is most likely that the bulk of the remanufacturing dealers’ cores would be supplied from their own customer base.

Due to the lower expected quantity for a single dealer, the limited capacity of the dealers overall, and the homogenous product mix not having a greater impact due to the variance in condition of the cores, production systems like job shop or batch production seemed appropriate and in accordance with the matrix of subsection 3.3.3. In subsection 3.3.2 the strengths and weaknesses of these systems were presented; the higher innovativeness of the job shop does not benefit it much in this scenario while increased flexibility is very important due to the uncertainties of core availability. However, batch production reduces costs which would be crucial for the profit margins and therefore the dealer’s willingness to get involved in remanufacturing, while the system also promotes quality and conformity to specification. The largest detriment to batch production is its size, as most dealers have very limited amounts of space.

Prerequisites for implementing a remanufacturing process at these locations in terms of operational, logistics, and labor factors are presented in Table 9. These and additional factors have from the above reasoning and information from the current state been slotted into Figure 18 to create an overview of the total capabilities of this alternative.
Table 9 - Existent prerequisites for the decentralized alternative.

<table>
<thead>
<tr>
<th>Operational Factors</th>
<th>Logistics Factors</th>
<th>Labor Factors</th>
</tr>
</thead>
<tbody>
<tr>
<td>- Existing service protocol can be expanded upon for remanufacture</td>
<td>- Existing logistics channels can be utilized</td>
<td></td>
</tr>
<tr>
<td>- Production system with high cost due to low volumes</td>
<td></td>
<td></td>
</tr>
<tr>
<td>- Difficult to achieve a standardized process and quality assessment among all dealers</td>
<td></td>
<td></td>
</tr>
<tr>
<td>- Many different steps/actors drive up the price</td>
<td></td>
<td></td>
</tr>
<tr>
<td>- No scalability</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Figure 18 - SWOT figure for the decentralized alternative.

5.5.3. Centralized and Decentralized Combined

This alternative was a mix of the former two, combining any one of the centralized alternatives with the decentralized alternative of dealers performing the remanufacturing process. Therefore, the same remarks made in the previous subsections still mostly apply. A mixed approach would however lead to multiple flows of cores and remanufactured products, thus affecting each other. The quantities of cores returned would likely be the same, but the distribution of cores would raise issues needed to be solved. The remanufacturing dealers would still retrieve the bulk of their cores from their own
customer base, however the opportunity to gain support from other dealers would likely not exist as the cores acquired by those sources instead would be sent to the centralized alternative. This implies a reduced quantity of cores for both alternatives compared to the previous stand-alone cases.

A reduced quantity of cores would lessen the benefits of selecting a centralized alternative. The costs of establishing new facilities would be spread over fewer products, impacting the price of the remanufactured products. Some variants of production systems, like FMS or EPL, may not be as lucrative and effective if the utilization is low.

Utilizing only core service as a gathering method could also be problematic for this alternative, due to the possible differences in remanufacturing quality between the centralized and decentralized location. With such a service the demands on equivalent quality are high, and it is possible that the dealers cannot produce the same quality of remanufactured products as a more advanced production system with higher capacity owned by Husqvarna or a third party. Therefore, the customers might be more interested in purchasing the service from Husqvarna instead, circumventing their local dealer. This could result in another issue with a combined alternative, competition.

If both alternatives are used and provide their service or product to likely customers, the markets could overlap due to the reach of online channels. The affected customers interested in a remanufactured product would then need to make a choice, probably dependent on cost and perceived quality. As such the profits of both alternatives could be at risk due to need for competitive pricing and possibility of being passed over for the other alternative. On the other hand, accurate and differentiated targeting from the different alternatives could reap benefits from multiple markets without any internally caused intrusions.

Prerequisites for implementing a remanufacturing process at these locations in terms of operational, logistics, and labor factors are presented in Table 10. These and additional factors have from the above reasoning and information from the current state been slotted into Figure 19 to create an overview of the total capabilities of this alternative.

<table>
<thead>
<tr>
<th>Operational Factors</th>
<th>Logistics Factors</th>
<th>Labor Factors</th>
</tr>
</thead>
<tbody>
<tr>
<td>- Inconsistent quality</td>
<td>- Multiple weaker flows</td>
<td></td>
</tr>
</tbody>
</table>
5.6. Selection of Alternatives

When comparing the centralized alternatives some similarities emerged. All the alternatives could provide an opportunity to develop standardized processes and achieve remanufactured products with consistent quality. Some alternatives also shared big strengths and weaknesses; access to spare parts and logistics systems contra being big investments and missing competence nearby. In the SWOT matrices the difference in impact between the alternatives was however not conveyed. The spare parts warehouse has access to spare parts of most models while the manufacturing plants only carry parts of the recent models through production as well as all components produced in house for all active models. The logistics network connections of the manufacturing plants were greater in number and size compared to those of the spare parts warehouse, while the manufacturing plants would need to serve many more nodes at higher costs in a remanufacturing scenario. The costs of a bigger investment in building a new plant as well as hiring labor differed between countries and locations, possibly lowering costs to some extent for the manufacturing plants and new location alternatives. All alternatives that may require this kind of investment on the other hand gained the benefit of a facility designed for remanufacturing purposes, and the centralized alternative itself implied economies of scale (especially so for the manufacturing plants alternative which would possibly source cores from more than one region). A need for competence is more easily filled and developed on from locations close to the current activities of the company, as skilled workers are required for several steps of the remanufacturing process. This made the manufacturing plants with their current quality assurance activities and the spare parts warehouse with proximity to Husqvarna’s main hub even more attractive alternatives for the remanufacturing location.

Related to quality assurance was inspection of cores if inspection at the remanufacturing site is preferred. All centralized alternatives risk attaining unusable cores if no quality control is made at the collection center, but the cost of such an event would be increased with longer and more expensive transports. As the return flow of cores probably would pass the main distribution center if a centralized
alternative is chosen in order to reconcile the units the spare parts warehouse would likely be the cheapest transport alternative, or possibly the new location or third party depending on the transport arrangements that could be made. As the return flow most likely would pass the main distribution center it would impart additional stress on this location, and this was even more true for the manufacturing plants scenario where long-distance transport would need to be arranged. Normal activities being disturbed would also be a risk at the manufacturing plants if a re-prioritization of lines would be performed.

The final centralized alternative of using a third party was quite unique compared to the other centralized alternatives. It shared the benefits of consistent quality and economies of scale for the remanufacturer while eliminating the need for Husqvarna to involve themselves in the remanufacturing process possibly in any larger extent than as a supplier. The decentralized alternative shared many similarities with the alternative of using a third party, as both are external parties performing the remanufacturing process. However, the decentralized case would divide the market between many different actors, which probably would prevent each remanufacturing site to reach high volumes. This was also one of the most significant differences compared to all the centralized alternatives, since if economies of scale cannot be achieved, then the potential profitability of remanufacturing is lowered. Despite the many disadvantages of the decentralized case such as difficulty to achieve a consistent quality among all dealers and that the dealers require profit which lowers Husqvarna’s profitability, there were multiple advantages that outweighs these disadvantages. While being able to reach a wide market with the decentralized alternative, in both these cases Husqvarna’s initial investment would be small or non-existent. Husqvarna could as previously stated only reap the profits from remanufacturing by selling spare parts, thus making remanufacturing possibly profitable in both the short and long term.

External positioning of the remanufacturing process however would give power over to the other parties. Multiple steps and actors in the remanufacturing process could mean increased prices on the end products as all involved parties require profit. This could be especially true for the third-party alternative, as in that alternative, both Husqvarna and the dealers would probably be involved at least initially. There is also no real guarantee that Husqvarna’s own spare parts would be used in the remanufacturing, possibly cutting the company short of any profits of the process. Some sort of agreement would be desirable to avoid such a scenario. A worst-case scenario could be if the third-party remanufacturer decided upon acting as an independent remanufacturer, gathering cores themselves and buying spare parts from other suppliers, as this would cut out not only Husqvarna from the aftermarket but possibly their dealers as well.

Approaching remanufacturing with the combined alternative would inherit most advantages and disadvantages of the centralized and decentralized cases. However, additional drawbacks have been identified, while there were no clear benefits other than being able to reach an even wider market than the other alternatives. In the combined case the flow of cores and remanufactured products would be split between different channels making the remanufacturing supply chain complex, and it would even allow for an internal competition of cores, prices and resources. It implicated an increase in the amount of weaknesses, which lowers the possibility that this alternative would be economically sustainable, and therefore it is not be part of the upcoming NPV-analysis. It could however be useful in a transition period from Husqvarna’s current state to remanufacturing, as it allows Husqvarna to set up a small-
scale remanufacturing process which develops the remanufacturing procedure while it simultaneously can provide education to the dealers in the process.

Out of the six alternatives presented through SWOT-analyses in the previous section, three were chosen for the net present value calculations; the centralized alternatives of spare parts warehouse and third-party remanufacturing, and the decentralized alternative.
6. Economic Analysis

In this chapter the selected alternatives are analyzed with the aid of NPV-calculations. Variables and their associated assumptions are defined, formulas and calculations are presented, and finally the impact of estimated values used are investigated through a sensitivity analysis.

6.1. NPV Variables

Through the performed interviews and analysis of the remanufacturing alternatives, variables with economic impact on the different alternatives could be identified. Four categories were created to group the variables and exemplify their connections to the contents of the previous sections:

**Investment Cost** is a category made up of those costs that do not reoccur during the remanufacturing process but are mainly a one-time transaction. This category includes quantitative data connected to and collected in conjunction with the data of section 4.5, and subsections 4.4.1 and 4.6.2.

**Core Acquisition** handles the variables included in the flow of the remanufacturing system from the end customers to the remanufacturer. This category includes quantitative data connected to and collected in conjunction with the data of sections 4.3, 4.8, 5.2 and 5.3, and subsections 4.6.1, 4.6.2 and 4.6.3. Subsection 3.2.4 was utilized for theoretical return rates.

**Remanufacturing Process** consists of all variables intrinsic to the remanufacturing process itself. This category includes quantitative data connected to and collected in conjunction with the data of sections 4.2, 4.3, 4.5 and 4.6, and subsections 4.4.1, 4.4.2 and 4.4.3. Section 3.2 was utilized for the steps of the remanufacturing process.

**Sales of Remanufactured Products** is the final category that handles the variables included in the flow of the remanufacturing system from the remanufacturer to the end customers. This category includes quantitative data connected to and collected in conjunction with the data of sections 4.3, 4.8 and 4.9, and subsection 4.6.3. Subsection 3.2.3 was utilized for theoretical remanufactured product pricing.

The necessary variables for performing net present value calculations on the three chosen alternatives are presented in detail below in Table 11. Quantitative values of these variables were collected in accordance with subsection 2.3.2 through the interview study. The actual values of these variables could vary depending on the alternative investigated and are not noted in this work due to their sensitive nature as stated in section 2.4.
<table>
<thead>
<tr>
<th>Variable</th>
<th>Definition</th>
</tr>
</thead>
<tbody>
<tr>
<td>$I_{NM}$</td>
<td>Investment cost to buy required machines and tools</td>
</tr>
<tr>
<td>$I_{RE}$</td>
<td>Investment cost to perform remanufacturing worker education</td>
</tr>
<tr>
<td>$I_{SD}$</td>
<td>Investment cost to distribute expanded service documentations</td>
</tr>
<tr>
<td>$C_{AC}$</td>
<td>Available cores for remanufacturing per year</td>
</tr>
<tr>
<td>$C_{DP}$</td>
<td>Percentage of cores not collected by remanufacturing dealers but other dealers</td>
</tr>
<tr>
<td>$C_{IP}$</td>
<td>Incentive price offered for core</td>
</tr>
<tr>
<td>$C_{TC}$</td>
<td>Transportation cost dealer to remanufacturer</td>
</tr>
<tr>
<td>$P_{EC}$</td>
<td>Sales price of surely exchanged components</td>
</tr>
<tr>
<td>$P_{PC}$</td>
<td>Sales price of probably exchanged components</td>
</tr>
<tr>
<td>$P_{PE}$</td>
<td>Probability that probably exchanged components are exchanged</td>
</tr>
<tr>
<td>$R_{EC}$</td>
<td>Cost of surely exchanged components</td>
</tr>
<tr>
<td>$R_{LC}$</td>
<td>Labor cost of operators or workers</td>
</tr>
<tr>
<td>$R_{LF}$</td>
<td>Number of operators or workers</td>
</tr>
<tr>
<td>$R_{PC}$</td>
<td>Cost of probably exchanged components</td>
</tr>
<tr>
<td>$R_{RF}$</td>
<td>Rent cost of the remanufacturing facility</td>
</tr>
<tr>
<td>$R_{SP}$</td>
<td>Transportation cost of spare parts to remanufacturing location</td>
</tr>
<tr>
<td>$t_{IP}$</td>
<td>Time to inspect product</td>
</tr>
<tr>
<td>$t_{QP}$</td>
<td>Time to test quality of remanufactured product</td>
</tr>
<tr>
<td>$t_{RP}$</td>
<td>Time to remanufacture product</td>
</tr>
<tr>
<td>$t_{WP}$</td>
<td>Time for entire remanufacturing process $= t_{IP} + t_{QP} + t_{RP}$</td>
</tr>
<tr>
<td>$S_{CC}$</td>
<td>Transportation cost of sold product from centralized location</td>
</tr>
<tr>
<td>$P_{SP}$</td>
<td>Sales price of remanufactured product</td>
</tr>
</tbody>
</table>

In Table 12, simplifying assumptions for these NPV variables are presented. The assumptions also state how the variables have been varied in the sensitivity analysis.
<table>
<thead>
<tr>
<th>Variable</th>
<th>Assumption</th>
</tr>
</thead>
<tbody>
<tr>
<td>$I_{NM}$</td>
<td>Values estimated based on the cost of current production line(s) in Husqvarna’s manufacturing plants or the dealers’ service workshop. Sensitivity analysis lower value estimated as service equipment cost, higher value estimated as cost of two production lines</td>
</tr>
<tr>
<td>$I_{RE}$</td>
<td>All values estimated based on Husqvarna’s cost of providing the service education</td>
</tr>
<tr>
<td>$I_{SD}$</td>
<td>All values estimated based on the cost to distribute updated service manuals to all dealers</td>
</tr>
<tr>
<td>$C_{AC}$</td>
<td>All values estimated based on sales volumes, dealer experience and theoretical return rates</td>
</tr>
<tr>
<td>$C_{DP}$</td>
<td>Set to zero, assuming all dealers can perform remanufacturing or that cores are transported to correct site from the start. Otherwise should be estimated based on dealer sizes and dealer experience, not possible due to lack of data</td>
</tr>
<tr>
<td>$C_{IP}$</td>
<td>All values estimated based on dealer experience, Husqvarna expertise and second-hand online market. Incentive set as average value</td>
</tr>
<tr>
<td>$C_{TC}$</td>
<td>Husqvarna’s transport rates for 25 kg parcel. Fixed value</td>
</tr>
<tr>
<td>$P_{EC}$</td>
<td>Husqvarna’s price to external parties. Sensitivity analysis lower value estimated as lowest price with profit, higher value for possible price increase estimated as average of yearly increase in Consumer Price Index (CPI)</td>
</tr>
<tr>
<td>$P_{PC}$</td>
<td>Husqvarna’s price to external parties. Sensitivity analysis lower value estimated as lowest price with profit, higher value for possible price increase estimated as average of yearly increase in Consumer Price Index (CPI)</td>
</tr>
<tr>
<td>$P_{PE}$</td>
<td>All values estimated based on spare parts specialist experience and theoretical tendencies of customers returning cores with defects</td>
</tr>
<tr>
<td>$R_{EC}$</td>
<td>Husqvarna’s cost of acquirement. Fixed value</td>
</tr>
<tr>
<td>$R_{LC}$</td>
<td>All values estimated based on Husqvarna expertise. Either noted as Husqvarna’s total labor costs for operators, or salary rate of dealer service worker. Depends on chosen alternative</td>
</tr>
<tr>
<td>$R_{LF}$</td>
<td>For decentralized alternatives: Estimated based on lowest feasible even multiple of operators required for factory line. Sensitivity analysis lower value estimated as minimum need of operators, higher value set as factory line operator requirements. For decentralized alternative: All values estimated based on dealer employee data and experience</td>
</tr>
<tr>
<td>$R_{PC}$</td>
<td>Husqvarna’s cost of acquirement. Fixed value</td>
</tr>
<tr>
<td>$R_{RF}$</td>
<td>All values estimated based on the cost for renting and running a warehouse or workshop in Torsvik and the area required for the remanufacturing process</td>
</tr>
<tr>
<td>$R_{SP}$</td>
<td>Husqvarna’s current cost for shipping spare parts. Fixed value</td>
</tr>
<tr>
<td>$t_{IP}$</td>
<td>All values estimated based on dealer experience and Husqvarna expertise</td>
</tr>
<tr>
<td>$t_{QP}$</td>
<td>All values estimated based on Husqvarna expertise</td>
</tr>
<tr>
<td>$t_{RP}$</td>
<td>All values estimated based on service time or lead time at factory. Depends on chosen alternative</td>
</tr>
<tr>
<td>$t_{WP}$</td>
<td>-</td>
</tr>
<tr>
<td>$S_{CC}$</td>
<td>Husqvarna’s transport rates for 25 kg parcel (from distribution center or third party). Fixed value</td>
</tr>
<tr>
<td>$P_{SP}$</td>
<td>All values estimated based on market price of selected robots, dealer experience and theoretical remanufactured product pricing</td>
</tr>
</tbody>
</table>
None of the NPV formulas did include the remanufacturing time \( t_{WP} \) directly. For dealers it was assumed that the remanufacturing process would be only one of many work tasks their workers would perform, that is the workers would not be dedicated remanufacturing workers. Therefore, the time for the entire remanufacturing process was varied throughout the calculations and an impact on the NPV was presented in the upcoming sensitivity analysis, section 6.4. However, for the other cases there would be dedicated remanufacturing workers, and their labor costs were not based on the remanufacturing time directly, instead they were calculated on a yearly basis for a full-time worker. The time for the remanufacturing process was only considered by identifying if the numbers of workers had the capacity to handle the remanufactured volume.

### 6.2. NPV Formulas
The equations presented in this section are based on the NPV-formula (1) from subsection 3.4.2. These are case specific for the three identified feasible alternatives. For the third party and dealer alternative there are two formulas; one for Husqvarna and one for the remanufacturer. For the remanufacturing process to be successful, Husqvarna must be able to benefit from the process as well as the remanufacturer. All of the alternatives used the same discount rate \( r \) defined as Husqvarna’s internal weighted average cost of capital for the company of Sweden.

The used period for the NPV formulas was five years as the available data fitted this timeframe. Sales volumes used in the formulas was approximately six years old, and as lawn mowers are expected to be in working condition for at least ten years, this ensures that the cores used in the remanufacturing process should still be in a reasonable condition suitable for remanufacturing. In the cases where initial investments existed, they were considered small, and did not require a period longer than five years to pay off. The period is also reasonable according to theory, where it was stated that the investment period should be short as all investments reach an equilibrium in the long term (Myers, 1984).

Previously in the analysis it was stated that the Husqvarna and the third-party alternative required a new facility, which could either be built, purchased or rented. For the following economic analysis, the latter is chosen as it was difficult to estimate the cost of building or buying a new facility and because this approach was more suitable for a short investment period. However, in the long run, renting a facility would probably be costlier.

#### 6.2.1. Spare Parts Warehouse
\( NPV_{H1} \) or equation (2) is the net present value for Husqvarna regarding the centralized alternative of the spare parts warehouse:

\[
NPV_{H1} = -(I_{NM} + I_{RE} \cdot R_{LF}) + \sum_{t=1}^{n} \left( \frac{-(R_{LC} + R_{RF}) + C_{AC} \cdot \left( P_{SP} - (C_{TC} + C_{IP} + R_{EC} + R_{PC} \cdot P_{PE} + R_{SP} + S_{CC}) \right)}{(1 + r)^t} \right)
\]  

#### 6.2.2. Third Party
\( NPV_{H2} \) or equation (3) is Husqvarna’s net present value for the third-party alternative:

\[
NPV_{H2} = \sum_{t=1}^{n} \left( \frac{C_{AC} \cdot \left( P_{PE} + P_{PC} \cdot P_{PE} - (R_{EC} + R_{PC} \cdot P_{PE}) \right)}{(1 + r)^t} \right)
\]
\(NPV_{T2}\) or equation (4) is the net present value for the third party themselves:

\[
NPV_{T2} = -(I_{NM} + I_{RE} \cdot R_{LF}) + \\
+ \sum_{t=1}^{n} \left( \frac{-(R_{LC} + R_{RF}) + C_{AC} \cdot \left( P_{SP} - (C_{TC} + C_{IP} + P_{EC} + R_{SP} + (P_{PC} + R_{SP}) \cdot P_{PE} + S_{CC}) \right)}{(1 + r)^t} \right)
\] (4)

### 6.2.3. Decentralized

\(NPV_{H3}\) or equation (5) is Husqvarna’s net present value for the decentralized alternative:

\[
NPV_{H3} = -(I_{RE} \cdot R_{LF} + I_{SD}) + \sum_{t=1}^{n} \left( \frac{C_{AC} \cdot \left( P_{EC} + P_{PC} \cdot P_{PE} - (R_{EC} + R_{PC} \cdot P_{PE}) \right)}{(1 + r)^t} \right)
\] (5)

Finally, \(NPV_{D3}\) or equation (6) is the net present value for a remanufacturing dealer:

\[
NPV_{D3} = \sum_{t=1}^{n} \left( \frac{C_{AC} \cdot \left( P_{SP} - (C_{DP} \cdot C_{TC} + C_{IP} + P_{EC} + R_{SP} + (P_{PC} + R_{SP}) \cdot P_{PE} + R_{LC} \cdot t_{WP}) \right)}{(1 + r)^t} \right)
\] (6)

### 6.3. NPV Calculations

As previously mentioned in section 2.4, the data used for these calculations have not been presented in the report and the results have been adjusted to reflect the same calculation outcomes without presenting any real-world values. In Table 13 the adjusted net present values of the chosen alternatives are displayed:

<table>
<thead>
<tr>
<th>(NPV_{H1})</th>
<th>(NPV_{H2})</th>
<th>(NPV_{T2})</th>
<th>(NPV_{H3})</th>
<th>(NPV_{D3})</th>
</tr>
</thead>
<tbody>
<tr>
<td>21 496 823</td>
<td>17 850 094</td>
<td>3 646 729</td>
<td>17 191 890</td>
<td>21 430</td>
</tr>
</tbody>
</table>

From the initial calculations remanufacturing seems to be profitable for Husqvarna in all the presented alternatives, however, one should keep in mind that this is with assumptions of direct acceptance and sales to the market as well as the ability to collect and remanufacture all available cores. Furthermore, one should be aware of the risks involved with the latter two alternatives. If the third-party remanufacturer or the dealers would not be profitable they would have to stop their remanufacturing activities and end the collaboration with Husqvarna, effectively also removing Husqvarna’s source of income and made investments.

For these same variable values, payback periods were calculated for the alternatives, presented in Table 14. Due to the assumptions and the low or non-existent investments needed for some alternatives they almost immediately become profitable within the right circumstances. The payback periods also assume that all activities start immediately with no start-up periods.

<table>
<thead>
<tr>
<th>Payback(_{H1})</th>
<th>Payback(_{H2})</th>
<th>Payback(_{T2})</th>
<th>Payback(_{H3})</th>
<th>Payback(_{D3})</th>
</tr>
</thead>
<tbody>
<tr>
<td>4 months</td>
<td>Immediate</td>
<td>15 months</td>
<td>2 months</td>
<td>Immediate</td>
</tr>
</tbody>
</table>

65
6.4. Sensitivity Analysis

In Table 15 the variables of each net present value calculation were closely examined and adjusted within their possible intervals to determine their impact on the results. The table is interpreted together with Table 13, where a percentage value of at least -100 results in a negative NPV for the alternatives whose adjusted NPV is positive, and therefore resulting in a non-profitable investment. Details on how the estimations for the intervals were determined can be found in Table 12.

The percentage impact depends mostly on the chosen values which were identified for the sensitivity analysis intervals, and therefore the interpretation and comparison between the percentual value of the variables should not be conducted directly in terms of that small changes would result in a high impact. A high percentage could be the result of at least two different reasons; one being that the variable has a broad interval and therefore results in a considerable impact, while the other being that a small interval (therefore a small change) impacts the results significantly. The table shows the impact of how each variable with its maximum and minimum value affects the results compared to the expected or medium values of the variables.

<p>| Table 15 - Min/Max changes for the percentage impact spans of variables on each alternatives’ net present values. |</p>
<table>
<thead>
<tr>
<th>Variable</th>
<th>NPV&lt;sub&gt;h1&lt;/sub&gt;</th>
<th>NPV&lt;sub&gt;h2&lt;/sub&gt;</th>
<th>NPV&lt;sub&gt;T2&lt;/sub&gt;</th>
<th>NPV&lt;sub&gt;H3&lt;/sub&gt;</th>
<th>NPV&lt;sub&gt;D3&lt;/sub&gt;</th>
</tr>
</thead>
<tbody>
<tr>
<td>𝐼&lt;sub&gt;𝑁𝑀&lt;/sub&gt;</td>
<td>-6.56 / 6.52</td>
<td>-</td>
<td>-38.66 / 36.34</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>𝐼&lt;sub&gt;𝑅𝐸&lt;/sub&gt;</td>
<td>-0.01 / 0.01</td>
<td>-</td>
<td>-0.05 / 0.05</td>
<td>-0.77 / 0.77</td>
<td>-</td>
</tr>
<tr>
<td>𝐼&lt;sub&gt;𝑆𝐷&lt;/sub&gt;</td>
<td></td>
<td></td>
<td>-0.01 / 0.00</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>𝐶&lt;sub&gt;𝐴𝐶&lt;/sub&gt;</td>
<td>-77.74 / 23.76</td>
<td>-65.44 / 20.00</td>
<td>-137.94 / 92.74</td>
<td>-67.95 / 20.77</td>
<td>-65.44 / 20.00</td>
</tr>
<tr>
<td>𝐶&lt;sub&gt;𝐷𝑃&lt;/sub&gt;</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td></td>
</tr>
<tr>
<td>𝐶&lt;sub&gt;𝐼𝑃&lt;/sub&gt;</td>
<td>-59.08 / 47.26</td>
<td>-</td>
<td>-348.27 / 278.61</td>
<td>-</td>
<td>-190.55 / 152.44</td>
</tr>
<tr>
<td>𝐶&lt;sub&gt;𝑇𝐶&lt;/sub&gt;</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td></td>
</tr>
<tr>
<td>𝑃&lt;sub&gt;𝐸𝐶&lt;/sub&gt;</td>
<td>-</td>
<td>-95.92 / 21.89</td>
<td>-34.01 / 469.51</td>
<td>-99.59 / 7.21</td>
<td>-18.61 / 256.90</td>
</tr>
<tr>
<td>𝑃&lt;sub&gt;𝑃𝐶&lt;/sub&gt;</td>
<td>-</td>
<td>-0.35 / 0.06</td>
<td>-0.31 / 1.71</td>
<td>-0.36 / 0.06</td>
<td>-0.17 / 0.93</td>
</tr>
<tr>
<td>𝑃&lt;sub&gt;𝑃𝐸&lt;/sub&gt;</td>
<td>-1.01 / 0.13</td>
<td>-</td>
<td>-9.18 / 3.06</td>
<td>-0.48 / 1.44</td>
<td>-5.02 / 1.67</td>
</tr>
<tr>
<td>𝑅&lt;sub&gt;𝐸𝐶&lt;/sub&gt;</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td></td>
</tr>
<tr>
<td>𝑅&lt;sub&gt;𝐿𝐶&lt;/sub&gt;</td>
<td>-0.53 / 0.53</td>
<td>-</td>
<td>-3.14 / 3.14</td>
<td>-</td>
<td>-1.30 / 1.33</td>
</tr>
<tr>
<td>𝑅&lt;sub&gt;𝐿𝐹&lt;/sub&gt;</td>
<td>-31.59 / 5.18</td>
<td>-</td>
<td>-188.33 / 29.71</td>
<td>-1.28 / 1.28</td>
<td>-</td>
</tr>
<tr>
<td>𝑅&lt;sub&gt;𝑃𝐶&lt;/sub&gt;</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td></td>
</tr>
<tr>
<td>𝑅&lt;sub&gt;𝑅𝐹&lt;/sub&gt;</td>
<td>-1.01 / 0.19</td>
<td>-</td>
<td>-5.94 / 1.11</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>𝑅&lt;sub&gt;𝑆𝑃&lt;/sub&gt;</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td></td>
</tr>
<tr>
<td>𝑡&lt;sub&gt;𝐼𝑃&lt;/sub&gt;</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td></td>
</tr>
<tr>
<td>𝑡&lt;sub&gt;𝑄𝑃&lt;/sub&gt;</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td></td>
</tr>
<tr>
<td>𝑡&lt;sub&gt;𝑅𝑃&lt;/sub&gt;</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td></td>
</tr>
<tr>
<td>𝑡&lt;sub&gt;𝑊𝑃&lt;/sub&gt;</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-12.37 / 12.37</td>
<td></td>
</tr>
<tr>
<td>𝑆&lt;sub&gt;𝐶𝐶&lt;/sub&gt;</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td></td>
</tr>
<tr>
<td>𝑃&lt;sub&gt;𝑆𝐿&lt;/sub&gt;</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td></td>
</tr>
<tr>
<td>𝑃&lt;sub&gt;𝑆𝑃&lt;/sub&gt;</td>
<td>-89.80 / 89.80</td>
<td>-</td>
<td>-529.36 / 529.36</td>
<td>-</td>
<td>-289.64 / 289.64</td>
</tr>
</tbody>
</table>
The variables have only been changed one at a time, which could lead to interaction effects between variables are missed (Czitromo, 1999; van Groenendaal, 1998). In the formulas (see section 6.2) the only time major scaling could occur would be when changing multiple variables at once. Mainly involved in such scaling would be the remanufactured volume ($C_{AC}$), as it affects the net present value greatly through direct multiplication with several variables in all formulas. A change in this variable in combination with one or more of the variables it multiplies would amplify the positive or negative impact on the net present value. Other combinations such as the number of workers ($R_{LF}$) and the labor costs ($R_{LC}$) could also lead to scaled impacts on the net present values. However, the minimum number of workers for $R_{LF}$ in the third-party alternative results in a non-profitable investment, and therefore would an increase of the labor costs only further worsen the result. For the other alternatives the worst cases for these two variables do not impact the net present values much, and therefore neither would the combined worst cases.

Additionally, there are more variables that should also be considered in pairs or groups. An example of this is the numbers of workers, the number of remanufactured products and the investment cost to buy machines and tools ($I_{NM}$) for the spare parts warehouse and third-party alternatives. The number of workers must be scaled to have the capacity to handle the volume, while the volume also affects which investments that must be implemented. High volumes mean that a more advanced and costly production system is needed, while the opposite applies for low volumes. But as the number of workers would only be scaled upwards if there is a need to handle additional volumes, the increased labor cost would always be covered by the additional profit that the quantity provides. For a decreased volume, the labor costs should ideally go down, meaning that the negative effects on the profitability instead would be diminished.

The sales price of surely exchanged components ($P_{EC}$) lowers the value for $NPV_{H2}$ and $NPV_{H3}$ as it removes most of the margin on the spare parts that Husqvarna sells to the remanufacturers, which is also the reason why $NPV_{T2}$ and $NPV_{D3}$ could become very profitable. However, the spare parts price is set by Husqvarna, and it is therefore unlikely that it would be lowered much to benefit the remanufacturers. Therefore, this variable is not considered a risk that Husqvarna themselves must consider.

Other variables whose intervals had a significant impact on the alternatives net present value was the incentive price of the core ($C_{IP}$), the sales price of the remanufactured lawn mower ($P_{SP}$), along with the available cores for remanufacturing ($C_{AC}$). The estimation of the latter was uncertain, because of the complexity and uncertainty of the core acquisition process as stated in subsections 3.2.3 and 3.2.4. Therefore, Figure 20 was added to more clearly show how the volume of remanufactured products affect the net present value. The figure depicts how the formulas linearly depend on the volume from low to high, where the middle volume value corresponds to the adjusted NPV shown in Table 13. To ease the visual comparison, note that $NPV_{D3}$ has been changed to include all (311) dealers from being for each dealer separately as before.
There is a risk for $NPV_{T2}$ to reach a negative value at low volumes, at those levels making the third-party alternative an unfeasible one. This together with the incline of the $NPV_{H2}$ curve being flatter than that of the $NPV_{H1}$ means the third-party alternative would never be the best alternative economically for Husqvarna. For remanufacturing with low volumes, the decentralized alternative was shown to be the most profitable for Husqvarna by a slight margin. Even a remanufacturing volume of one unit is profitable for the dealers and results in a positive $NPV_{D3}$, however for Husqvarna’s profitability, a positive $NPV_{H3}$, the quantities must be larger. Higher volumes clearly make $NPV_{H1}$ the most profitable alternative, but since Husqvarna lacks a direct communication channel to most of their customers it should be reasonable to assume that the probability of Husqvarna acquiring a high volume of cores is significantly lower than that of the decentralized alternative, as the dealers would not be directly involved in the process. It could therefore result in that Husqvarna could benefit more from the decentralized alternative as $NPV_{H3}$ for high volumes is larger than $NPV_{H1}$ for low volumes as shown in Figure 21.
The incentive- and sales price both seem to have opposite linear effects on the NPV of the alternatives, as can be seen in Figure 22 and Figure 23 respectively. These figures have been altered the same way as Figure 20 to ease visual comparison, where $NPV_{D3}$ was changed to include all dealers instead of only the net present value of one dealership. $NPV_{H2}$ and $NPV_{H3}$ are of course exceptions to the aforementioned opposite linear effects as they do not include these variables. In their alternatives Husqvarna would only be concerned with the volume, price and sales of components to their respective remanufacturers, and therefore these net present values are constant for the examples.

The differences in result between $NPV_{H1}$, $NPV_{T2}$ and $NPV_{D3}$ are also stable (see Figure 22 and Figure 23). The first alternative always provides a more beneficial outcome, however, one should here remember the increased possible negative volatility of $NPV_{H1}$ (and $NPV_{T2}$) due to uncertainty in the number of available cores. In the figures the break-even points may act as signifiers for the alternatives to how the variables can be changed while still aiming to be profitable. One could offer higher incentives, possibly making returning cores more interesting for the end customers, which could increase return rates. Moreover, the opportunity to sell the remanufactured product at a lower price would be advantageous for competitiveness against rivaling low-cost products.

Figure 21- NPV of H1 (orange) and H3 (red) with expected volume ratio indicated with arrows.
Figure 22 - NPV of the alternatives with varied incentive offered.

Figure 23 - NPV of the alternatives with varied sales price.
7. Results and Conclusions

This chapter summarizes the findings from the performed study, presenting the answers produced for the research questions and the purpose.

7.1. Research Question 1

What type of production system is most suitable for remanufacturing given a certain quantity?

The most suitable production systems for Husqvarna, and remanufacturing in a general context (initially presented in Table 4) are summarized in Table 16 below.

The production systems were analyzed in section 5.4, where the theory of the production systems was combined with a theoretical remanufacturing process. It was identified that a production system for remanufacturing must be capable of handling products, i.e. cores of different quality, and that the arrival rate of cores to the process likely would be uncertain. Firstly, this excluded the production system continuous flow, as its requirements were inputs of low variety and an even arrival rate to reach the potential of the system. Secondly, the production system JIT was excluded as well. JIT brings complexity to the production, since it requires e.g. deliveries just in time, which a remanufacturing system may have difficulties to provide.

The remaining production systems were assessed as suitable for remanufacturing, although the low flexibility of the EPL system could have difficulties with the varied conditions of the cores but should work nonetheless if the weaknesses of the system could be identified and avoided. These production systems reach their fullest potential at different quantities, which was depicted in Figure 5. Job shop reaches its potential at low volumes, while EPL at high. Batch flow, FMS and OPL are suitable for volumes ranging between low to high, where batch flow is in the lower end of the range and OPL is in the upper.

For Husqvarna specifically, it was identified that they do not have much experience in using a highly automated production system for their robotic lawn mowers, therefore the production systems (FMS and EPL) which depend on automatization were identified to not be the most suitable production systems for remanufacturing as they would add uncertainty and risk to the process when considering Husqvarna’s current state.

Table 16 - Summary of the suitability of the production systems for remanufacturing.

<table>
<thead>
<tr>
<th></th>
<th>Suitable for remanufacturing</th>
<th>View from Husqvarna</th>
<th>Volume</th>
</tr>
</thead>
<tbody>
<tr>
<td>Job Shop</td>
<td>Yes</td>
<td>Yes</td>
<td>Very Low</td>
</tr>
<tr>
<td>Batch Flow</td>
<td>Yes</td>
<td>Yes</td>
<td>Low</td>
</tr>
<tr>
<td>OPL</td>
<td>Yes</td>
<td>Yes</td>
<td>Medium</td>
</tr>
<tr>
<td>FMS</td>
<td>Yes</td>
<td>Risky</td>
<td>Low</td>
</tr>
<tr>
<td>JIT</td>
<td>No</td>
<td>No</td>
<td>Low to Medium</td>
</tr>
<tr>
<td>EPL</td>
<td>Yes</td>
<td>Risky</td>
<td>High</td>
</tr>
<tr>
<td>CF</td>
<td>No</td>
<td>No</td>
<td>Very High</td>
</tr>
</tbody>
</table>
7.2. Research Question 2
Which prerequisites in terms of operational, logistics and labor factors do different locations in the supply chain have for a remanufacturing process?

Tables 5 – 10 in section 5.5 present the prerequisites each investigated location has in terms of operational, logistics and labor factors for implementing a remanufacturing process. All the alternatives and their respective factors from these tables are summarized in Table 17 below.

Operational factors prevalent in multiple alternatives include; facilities made for the purpose at hand, economies of scale, standardized process and consistent quality (in some other cases uncertain quality), and many different steps/actors which results in higher costs. These are, apart from the last factor, fundamentally all positive influences for a remanufacturing process. Facilities made for the purpose at hand promotes efficiency throughout the entire remanufacturing process, allowing for reduced lead times of possible inspection, disassembly, cleaning, assembly, and quality assurance activities. Centralized remanufacturing gives the opportunity for economies of scale, further lowering total cost beyond the reduced use of materials. A consistent quality of the remanufactured products is important for the Husqvarna brand, as quality is one of the premier competitive priorities of their products. If they themselves are to offer previously used products, these products must uphold the same standards as any other Husqvarna robotic lawn mower. A customer would most likely expect certain levels of performance from their brand, and if this could not be provided the remanufactured sales would suffer. Finally, the increased price of the remanufactured product due to handling in many multiple steps could make the product less appealing to some of the intended new markets with lower comfortable price ranges.

The existent logistics factors as prerequisites for remanufacturing range in comparison from good to poor between the alternatives. Availability of a logistics network and access to spare parts are the two most common logistics factors impacting the implementation of a remanufacturing process. The ability to utilize an already existent logistics network can cut costs on the multiple transports of cores, spare parts and finished goods necessary throughout the entire remanufacturing process. If spare parts are available in close proximity to the remanufacturing facility, transport costs can be reduced yet again. The opposite applies if spare parts are not as easily accessible.

Regarding labor factors for remanufacturing, the main focus revolves around competency, as some of the steps in the process require skilled workers. Such workers may imply a higher labor cost, but without them error occurrences would most likely be commonplace. Either the individuals possessing the required skills would need to be transferred to the remanufacturing facility, or other workers would need to be trained, both alternatives incurring costs either in filling the gap left behind by the transferred personnel or by carrying through training for the other workers. The necessary knowledge can be taught and further developed on, but if that would be the case a source of knowledge is needed. Even if the existing competency would not be transferred over to work in the remanufacturing process, a close proximity to it could be useful for such educational reasons.
<table>
<thead>
<tr>
<th>Alternative</th>
<th>Operational Factors</th>
<th>Logistics Factors</th>
<th>Labor Factors</th>
</tr>
</thead>
<tbody>
<tr>
<td>Spare Parts Warehouse – Torsvik</td>
<td>- Facilities made for the purpose at hand&lt;br&gt;- Economies of scale production&lt;br&gt;- Standardized process and consistent quality</td>
<td>- Logistics network available&lt;br&gt;- Logistics network available</td>
<td>- Must build up the competency&lt;br&gt;- Located near the main hub with varying competences</td>
</tr>
<tr>
<td>International Manufacturing Plants</td>
<td>- Greater economies of scale production&lt;br&gt;- Standardized process and consistent quality&lt;br&gt;- Remanufacture may interfere with normal activities</td>
<td>- Logistics network available&lt;br&gt;- Spare parts close&lt;br&gt;- Long and expensive transports</td>
<td>- Competences in production and quality</td>
</tr>
<tr>
<td>New Location</td>
<td>- Facilities made for the purpose at hand&lt;br&gt;- Economies of scale production&lt;br&gt;- Standardized process and consistent quality</td>
<td>- Needs access to spare parts&lt;br&gt;- Logistics channels must be built from scratch</td>
<td>- Must build up the competency</td>
</tr>
<tr>
<td>Third Party</td>
<td>- Economies of scale production&lt;br&gt;- Standardized process with consistent quality&lt;br&gt;- Many different steps/actors drive up the price</td>
<td></td>
<td>- Utilizes third party which has experience in areas Husqvarna do not&lt;br&gt;- Third party has the potential to become too independent</td>
</tr>
<tr>
<td>Decentralized</td>
<td>- Existing service protocol can be expanded upon for remanufacture&lt;br&gt;- Production system with high cost due to low volumes&lt;br&gt;- Difficult to achieve a standardized process and quality assessment among all dealers&lt;br&gt;- Many different steps/actors drive up the price&lt;br&gt;- No scalability</td>
<td>- Existing logistics channels can be utilized</td>
<td></td>
</tr>
<tr>
<td>Combined</td>
<td>- Inconsistent quality</td>
<td>- Multiple weaker flows</td>
<td></td>
</tr>
</tbody>
</table>
7.3. Research Question 3

What is the economic feasibility of remanufacturing for the locations in the supply chain?

Economic feasibility of the evaluated alternatives is presented in Table 18. Definitions of the NPV formulas and the variables they contain can be found in section 6.2.

Due to the uncertainty of core acquisition management the third-party alternative was considered to be risky in its economic feasibility and profitability, despite a positive NPV. The spare parts warehouse alternative shares the characteristic of uncertainty, but due to higher margins does not run the same risk and is consistently a better alternative for Husqvarna than enlisting a third party for remanufacturing.

The other two alternatives, spare parts warehouse and decentralized, were both considered feasible. Both alternatives possessed positive, sufficiently high net present values, and control over most variables that would impact the results noticeably or push the NPV to an unprofitable or negative value. For the same collected quantities of cores, $NPV_{H1}$ would be higher and provide the more profitable alternative for Husqvarna in all cases except for very low volumes. However, as discussed previously in section 5.2, the acquisition of cores would most likely be more effective if the decentralized alternative were chosen. For higher quantities of collected cores compared to those collected in the spare parts warehouse alternative, $NPV_{H3}$ could become higher than $NPV_{H1}$ as seen and discussed in section 6.4, Figure 20. This relation and the fact that the total amount of cores collected with the decentralized alternative would most likely outnumber any other alternative and would thus make the decentralized alternative the most profitable one.

Table 18 - Summary of the feasibility of location alternatives and their adjusted results from NPV calculations.

<table>
<thead>
<tr>
<th>Alternative</th>
<th>Economic Feasibility?</th>
<th>Adjusted Net Present Values</th>
</tr>
</thead>
<tbody>
<tr>
<td>Spare Parts Warehouse – Torsvik</td>
<td>Yes</td>
<td>$NPV_{H1}$ 21 496 823</td>
</tr>
<tr>
<td>Third Party</td>
<td>Risky</td>
<td>$NPV_{H2}$ 17 850 094</td>
</tr>
<tr>
<td>Decentralized</td>
<td>Yes</td>
<td>$NPV_{H3}$ 17 191 890</td>
</tr>
</tbody>
</table>

7.4. Purpose

The purpose of this project is to investigate how to incorporate remanufacturing of robotic lawn mowers into an existent system with a forward supply chain, and the economic consequence of such an incorporation.

This will be realized by proposing and evaluating multiple cases (or alternatives) of remanufacturing at different locations in the extended supply chain.

The investigation of how robotic lawn mowers could be remanufactured started by identifying how Husqvarna operates as a company. This was presented in the current state, which then was used to build up different alternatives for remanufacturing. Four centralized alternatives at different locations in a possible extended supply chain were established; a spare parts warehouse in Torsvik, the original manufacturing plants, a new location and enlistment of a third party. A decentralized alternative with
the dealers and a combined approach were also proposed. All of these were evaluated with the frame of reference as basis together with the data provided by different parties from Husqvarna, and then the alternatives were assessed with the help of a SWOT analysis which determined for each alternative whether it was analyzed further in the economic analysis. The NPV calculations in the economic analysis evaluated the profitability of remanufacturing. The result of this was presented in this chapter for Research Question 3.

To ease the investigation of the remanufacturing process suitable production systems and operational, logistics, and labor factors were identified. The analysis of production systems for remanufacturing provided information about which systems that could be used in the different alternatives, while the prerequisite factors eased the understanding of what must be considered when assessing or implementing a remanufacturing system at one of the investigated locations. These were then presented as the results and conclusions for Research Questions 1 and 2 respectively.
8. Discussion and Recommendations

This chapter discusses the ethical impacts and considerations of the work and how its contents relate to sustainable development. Generalizability and limits of the study methods and data are discussed. Finally, some recommendations for Husqvarna on how to act on the presented information and recommendations for possible future work on the subject are offered.

8.1. Ethics

Throughout this study ethical consideration has been conducted to ensure that no unethical principles have been applied which would damage the appearance of the result at a later stage. The investigators signed a non-disclosure agreement with Husqvarna to prevent that any confidential information used in the study would be spread to the public. All information gathered from Husqvarna must and have been presented to Husqvarna before the publication of the report, which allowed Husqvarna to redact or modify sensitive data to protect their competitiveness and their stakeholders’ interests. This means that some of the data in this report has been fabricated, but when this occurred the reader was notified and the effects on the results affected by the modification were explained to ensure that the study’s credibility and reliability were not damaged (see e.g. section 6.3). Furthermore, all information from other sources has been cited according to scientific standards to avoid plagiarism and to follow research ethical guidelines.

Data from interviews were gathered during this project, but personal information about the interviewees were kept to a minimum. Personal data which did not benefit the study such as social factors were not gathered or stored in any way. The only personal data stored about the interviewees were their names and job title, but the names were redacted from the report. The job titles were presented as they were required for the replicability of the study and to create credibility, but only in a summarized way to protect the integrity of the interviewees. The interviews were recorded after asking for consent to be used during the study, but the material was not spread to any other party or used elsewhere.

The study itself aims to introduce remanufacturing for robotic lawn mowers with the purpose of allowing Husqvarna to offer a product that benefits themselves and the market in an ethical way by providing a product which is ethically accepted in today’s society.

8.2. Sustainability

Sustainable development is an increasingly important aspect of scientific research in fields such as supply chain management (Beske & Seuring, 2014), manufacturing strategy (Sarkis, 2001), and operations management (Kleindorfer, et al., 2005). We discuss the possible impacts from this work on three domains of sustainability; economic, social and environmental. A sustainable outcome can only be achieved if all of the dimensions are fulfilled simultaneously as depicted in Figure 24.
8.2.1. Economic

The purpose of this report includes evaluation of economic factors, and one would be hard-pressed not to find ties to economic sustainability throughout the work from its introduction to conclusion. Circular economy as a concept was explained in section 3.1. It has benefits towards all three domains of sustainability, where economic benefits include access to emerging business models and reduction of waste in materials used. As this report aimed to investigate the alternatives of applying an aspect of circular economy in remanufacturing to modern industry these benefits are promoted to acting companies through the positive results of our investment calculations. Further benefits are presented in subsection 3.2.1 including reduced costs, aftermarket protection, increased competitiveness and increased attractiveness to certain markets.

Any profit produced from application of the presented recommendations would primarily benefit Husqvarna and their stakeholders. One could also argue that the added market growth from any profit produced would in itself be beneficial for society as a whole.

8.2.2. Social

In excess of the economic benefits of remanufacturing, the implementation of one of the presented alternatives in this report would entail a business expansion of some sort, employing a larger workforce at the least or even being the start of construction projects for new facilities. The job opportunities provided by such a venture would increase social support and responsibility. However, depending on the long-term outcome of the chosen alternative smaller dealers may be phased out impacting the same factors negatively.

Job creation is one of the social benefits remanufacturing companies themselves point out, together with increased accessibility of their product (Sundin, et al., 2016). Selling a premium remanufactured product at a lower price than the original counterpart or offering leasing services could present the opportunity for new markets and communities to benefit from the product who could not comfortably do so before.
8.2.3. Environmental

As previously mentioned circular economy impacts all domains of sustainability, and environmental sustainability especially so. From section 3.1 reduction of waste and used materials have already been mentioned in economic sustainability, being direct by-products of striving after a regenerative system with prolonged and iterative use of products and materials. Beyond these, multiple benefits like potential for reduced consumption of energy and emissions of greenhouse gases like CO₂ have been pointed out by other researchers as outlined in subsection 3.2.1.

Implementation of the presented alternatives in this report does however most likely constitute increased amounts of transportation, which would be made by truck. The emissions of these vehicles would have a negative environmental impact.

8.3. Generalizability

In its purpose and execution this study focused on remanufacturing of robotic lawn mowers specifically. The results and reasoning performed would however be applicable to other products, the extent of course dependent on the similarities. Somewhat technically advanced products, with a primary focus on consumer markets but also commercial customers would be the most applicable. Furthermore, the company Husqvarna was the target of the study. Other companies with similar structure of their supply chain would also have more direct use of the results in this report.

The scope of the study was limited to the company Husqvarna in the Swedish region. Sales of robotic lawn mowers are not limited to this region but part of their global leadership in outdoor power products. The same flows of materials and supply chain structure may not apply in all regions where the product is sold but would however most likely follow a comparable organization. This applies especially to geographically close regions, for example the other Nordic countries, Germany and the Netherlands.

For the calculations, data regarding model 220 of the Automower product family was used. Husqvarna’s different models of robotic lawn mowers differ mostly in software, and no major differences exist in the basic design. The different models are produced in similar production lines and have the same business models and service offers available. This implies similar prerequisites for a remanufacturing process, the main difference being the sales volumes and costs of the product and its components. Further apart from those models, the 220 is however also not produced actively any longer. It is though still in widespread use, like the newer models, and as these other models eventually also will approach the end of their lifetime the line of reasoning made in this report may become even more applicable to those models as well. However, the same formulas may be used if data is available for another model to calculate the exact economic feasibility of that model.

Any manufacturer with interest in remanufacturing could benefit from the results of Research Question 1. The production system analysis for remanufacturing presents tangible recommendations in terms of suitability of the production systems, and companies with similarities to Husqvarna could also benefit from the additional analysis regarding their production.

The results of Research Question 2 highlight operational, logistics, and labor prerequisite factors for different alternatives of remanufacturing systems, which impacts the decisions of incorporating remanufacturing into an existent supply chain. For other companies interested in remanufacturing...
similar factors would likely be present for their possible alternatives of implementation, and the factors presented in Table 17 could act as support for identifying resembling factors in their own supply chain.

Research Question 3 on the other hand is more of interest only for Husqvarna and stakeholders to the company, as it calculates the specific economic feasibility of the presented alternatives.

8.4. Limitations
The selected method of an interview study to gather data for the current state had weaknesses in bias, as discussed and addressed in section 2.6, as well as in reach. Additional information could have been collected with a survey study to expand the reach, targeting the dealers to gain a more unified and complete picture of how the dealerships handle the robotic lawn mowers in general and their aggregated opinions. Such a study could have improved the accuracy of estimations regarding collection of cores, time for remanufacturing, amounts of workers, and more, possibly even giving estimations for \( C_{DP} \) (percentage of cores not collected by remanufacturing dealers but other dealers).

An alternative to the economic analysis and NPV calculations could have been a simulation study, where the proposed alternatives would be modelled and run with stochastic variables and distributions. Such variables would however be even harder to estimate than the spans collected for the NPV calculations, and the simulation study would most likely produce the same results as the calculations with the same available data. This should also generally stand true to other methods of investment calculations.

If the collected data used in the NPV calculations is faulty the results would be at a high risk of changing, as some variables as shown in the sensitivity analysis have the potential to on their own make an alternative unprofitable. These data issues were addressed in section 2.6. However, if data from another model were to be used for the NPV calculations the results could also change, if the relation between costs of the components and the sales price of the product differ too much and if the sales volumes are too low. On the other hand, higher sales volume of another model could mean a more stable \( NPV_{T2} \) and the possibility of enlisting a third party for remanufacturing.

8.5. Recommendations for Husqvarna
The project concluded that there are multiple profitable alternatives that Husqvarna could use to implement remanufacturing. It is therefore recommended to implement a remanufacturing system for their robotic lawn mowers. Even though many decisions have been made in this project, there are many factors that do not affect the feasibility of remanufacturing directly which are left undecided for the real case scenario. This is for example exactly how inspection, core acquisition and business models for this process should be implemented. However, these are covered in the analysis of the report, where different approaches are stated, and in the cases when it was possible, commented upon how they could affect the remanufacturing process.

Additionally, the different alternatives for where the inspection is performed is also provided in section 5.3, but is left for a real implementation process to decide. In the economic analysis the incentive price for the cores used in the remanufacturing process was considered as independent of the quality, but this must not be the case as covered in section 5.3. In what form the incentive is given could also vary in any of the suitable closed-loop supply chain relationships that the analysis (section 5.2) derived from the frame of reference (subsection 3.2.4).
Husqvarna are in their current state dependent on the dealers, therefore it is recommended that the dealers are responsible for the possible remanufacturing process. This alternative seems to be the easiest to implement as the dealers should be able to handle the cores in terms of acquisition, inspection and sales more straightforwardly than Husqvarna could. But, if Husqvarna decides to approach the market in other ways, such as large-scale leasing or online sales through their own channels, then remanufacturing performed by Husqvarna could be the recommended approach, since Husqvarna will get more control over their end customers. By utilizing new business models, remanufacturing could be integrated into sales programs, such as Husqvarna Care. However, the overall satisfaction of the dealers must also be considered, since the dealers’ loyalty to the Husqvarna brand could diminish, affecting sales and services of products, if a certain future direction does not benefit them. It would also be helpful for Husqvarna to further investigate how many remanufactured products that can be sold based on the customer willingness to buy these products and to scale the investment calculations based on a forecast of the expected volume increase over time. When this has been performed, a further break-even analysis can be conducted to investigate which of the alternatives would be the best given a certain sales volume or to know if a transition to another alternative should be implemented later in the process for possibly a higher profitability.

Continuing on the business model, other factors such as warranty, brand and visual design of the remanufactured product were also left to be decided. A warranty period on the product would likely be important to market the remanufactured product as a product whose quality is equal to that of a new product. A brand on its own, or a new distinct color on the lawn mower’s body could also help distinguish the difference of the remanufactured product from ordinary second-hand lawn mowers. The remanufactured product could also be marketed as an environmentally friendly alternative by informing the customer of the general benefits of remanufacturing provided in subsection 3.2.1.

For a remanufacturing approach different from the economic analysis, Husqvarna are recommended to use the results of Research Question 1 and 2 to identify suitable production systems or operational, labor and logistics factors which must be considered. The benefits in subsection 3.2.1 can ease the understanding of the importance of remanufacturing, while the challenges in subsection 3.2.2 provides information about factors what must be considered and avoided when implementing remanufacturing.

### 8.6. Future Work

Further research building upon this thesis could be beneficial to both the fields of operations management and remanufacturing, and especially for companies in similar situations considering remanufacturing. The possibilities of including dealers more tightly to the remanufacturing process from the view of the OEM would be interesting to explore; how would one get the dealers more involved? How would different incentives to the dealers affect their participation? A more largely encompassing study targeting the dealers could investigate how to make the cooperation of remanufacturing more beneficial and profitable for both parties.

The result of Research Question 1 relies heavily on theory without actual validation from a real case scenario. Research could therefore be conducted in the field of production systems for existing remanufacturing systems, based on the same definitions used in this study and the research by e.g. Hill (1983; 1992; 2000), Miltenburg (2005; 2008) and Hayes & Wheelwright (1979). This would provide deeper understanding of how remanufacturing differs from manufacturing, which could be utilized to identify how already existing manufacturing theory can be applied or adapted to remanufacturing.
Other research that could help similar studies are further investigations of customers’ willingness to return cores based on product type, market and the value of the incentive to expand upon the results of e.g. Gentry (1999), Guide Jr et al. (2006) and Teunter et al. (2008). This would benefit the accuracy of estimations of the number of cores that can be expected for a new remanufacturing process. The effects of the closed-loop supply chain relationships could also be incorporated in such research.
9. References


Fox, R., 2008. *A brief critical history f NPV: is it the basis for project evaluation?*. Blackpool, UK, BAA Conference.


Appendix 1 – Interview Questions
Questions utilized in semi-structured interviews presented in general categories, no particular order.

General
What is your professional title? Your duties and everyday work tasks?

Explain competitive priorities to the interviewee. Could you rank these priorities for your product; cost, lead time, quality, performance, flexibility, and innovation?

Product Details
How many different models of robotic lawn mowers do you produce/sell?

What are the biggest differences between the products? Design and production-wise?

Average life-span of a robotic lawn mower?

Production
Current production system? Automatic or manually operated? Proportions?

What metrics are available?

Are you able to provide us with data concerning lead time, material costs, et cetera? If not, who would be?

How are production costs and/or prime costs calculated? Are calculations readily available?

How long does it take to produce one robotic lawn mower? Which step in the production is the most time-consuming?

How flexible is the production? Quantity and mix?

How long before a new product is produced with the same efficiency as old ones?

Are changes within production that affect the design of the product, that could in turn affect the remanufacturing process, common occurrences?

Education of new production staff, time and previous education necessary/common? The same question for service personnel. Average salary?

Are there different levels of education for production staff as for service personnel or is experience the only veritable factor?

Is there enough competence at the factories to support a remanufacturing process?

Is there capacity and room for a remanufacturing process at the factories?

Quality Assurance
How is the quality of a manufactured product controlled? Could that process be applied to a remanufactured product?
What happens to a manufactured product that does not clear all quality tests? Could such products be introduced to the remanufacturing process?

Is there leftover capacity in quality assurance at the factories available for use in a remanufacturing process?

**Components**

What components are produced in-house in the factories?

Are component prices dependent on quantity? To what extent?

Are there minimum order quantities for components that could impact decision making?

What does every component in the product cost for Husqvarna and on the other hand for the end customer? Material and manufacturing costs?

What components of the product are of greatest significance in terms of cost? Order of priorities? Why do these products stand for that amount of the cost? Are these components often in need of replacement?

Is any special equipment required to replace any of the components?

What components of the product would need to be replaced in a remanufacturing process? What components can be improved upon to make such a process easier?

**Supply Chain**

What is the general structure and flow of the current supply chain?

How are products transported at all intermediary steps? Transport costs?

What types of warehouses exist today? Main warehouse? Distribution centers?

What possibilities exist to transport cores through a return flow? Where would be a good place for a collection center for said cores?


**Spare Parts**

Spare part prices?

Are bootleg spare parts a concern for Husqvarna at this time?

How many spare parts warehouses exist today? Sizes?

Where are the spare parts warehouses located? Would that/those be able to supply a remanufacturing process with the appropriate parts needed, or would such components need to be ordered from a supplier? Could the main factories assist with any components?

Are all spare parts constantly available from the warehouses? Could one build an entire product out of spare parts so to speak?
Any spare parts there is usually a shortage off? That could be worsened by an increase in demand?
From where are the spare parts ordered? How long are the lead times? How common are those articles with long lead times in need of exchange during service?
Are all spare parts directly transported to warehouses or factories, or could dealers get a direct delivery?
How much surface area is available at the spare parts warehouse in Torsvik? Not used? Is there room to expand the warehouse?
What expertise do the warehouse workers have about the products? Do they only perform warehousing or other activities?

**About Dealers**
Holistically, how does the dealer system work?
To what extent are repairs performed at the dealers today? Are any products forwarded for greater repairs? If so, how many?
Are any specific models harder to service than others? More time-consuming?
What does Husqvarna have to earn on service provided by the dealers?
What dealers do currently offer winter storage for their customers? How many?
Some dealers pick up the product from the customer for service and/or winter storage. Is this something Husqvarna have helped develop or an initiative fully on the dealer’s side?
What sort of education would be needed to be able to exchange or recondition most of all the parts in the product? Who in the supply chain would currently be the most suitable for such assignments?
What is the general view on remanufacturing? On the service process in general?
Could the dealers take responsibility for collecting cores? Would they have the capability?
How many dealers would have the capacity and capability to take on a remanufacturing process?
How much space is available to dealers? Enough for a remanufacturing process at current locations?
Do the dealers have access to required tools and/or machines? If need to purchase, what would be the cost?
How much of the profit would the dealers require if they took part in the remanufacturing process?
How would Husqvarna gain benefits economically from such an arrangement? Only through spare parts? Rental of machines or personnel?
How should we approach the dealers with our questions? Are you to contact them first and give them a word of warning or is all the communication up to us?

**Remanufacturing**
Explain remanufacturing to the interviewee. What is your view on remanufacturing?
Where would you think a remanufacturing process would fit in with Husqvarna? Possible locations and alternatives?

From Husqvarna’s current view and available knowledge, how would a remanufacturing process look like today based on your views?

Some components like the engines seem to be expensive components that break down after extended use. Based on the most common causes of breakdown, would it be possible to repair such components? What would be required of the product and service personnel? Would such a process benefit from regular check-ups of the expensive and critical components?

**Investments**

What is the process at Husqvarna in investigating a possible investment?

What methods are used to perform calculations about the economic feasibility of investments?

What discount rate or similar rate do you use as a starting point in your calculations?

From what sources do you get your internal data?

How would you go about investigating the economic feasibility of a process like remanufacturing?

**Market**

Current business models? Target markets for these?

Total yearly sales?

Profit margins?

How large are your B2B deals? Leasing?

Returning customers? Due to upgrades? Do these return their old products?

Do you see market opportunities for used/remanufactured products? If they are cheaper?

Desired sales price of remanufactured product? Or desired profit margin of the same?

How do you think introduction of such a product would affect current product sales?

Where would one sell such a product? Online? Dealer?

How many active products fit for remanufacturing are out in the market today? From this what could a feasible quantity of returned remanufacturable products be?

Which models of the product can be remanufactured? Are those models produced in the same manufacturing system?

Would the remanufacturing process be affected in any way if the resulting products were sold as a different brand?

What does the end customer do with a no longer functioning product? Recycle? Throw away?
Are used products sold on online second-hand markets today? What is the state of the second-hand market overall currently?

**Husqvarna Care**

What is Husqvarna Care?

Which customer segments will Husqvarna Care be offered to?

Is there any planned difference between the service and repair from Husqvarna Care and the current service offer provided by dealers?

What would be the standard cost of the Care service?

Will this service be implemented in Sweden? If so, when?

Would the current Care service be compatible and expandable with remanufacturing?

What would be an approximate monthly leasing price for a robotic lawn mower? Including remanufacturing?

**For Dealers**

How long have you sold Husqvarna products, more specifically the robotic lawn mowers?

How long have you offered service of these products? Winter storage?

What other services do you provide?

How long does it take to perform a service when going through all steps?

What is included in the service? What has to be additionally purchased by the customer?

Do you tend to follow the checklist for service provided by Husqvarna? If so, do you think the steps and instructions are clear?

Which components tend to break or be in need of replacement?

How long does it take before you are well familiar with and able to perform all steps of the service process?

What tools have you had to contribute with to the service process. Have you received any specialized tools from Husqvarna? Other solutions?

What is your opinion about the education you have received? Sufficient? In need of an update?

How do you receive updates on service (new checklists, models, directives)?

What is your perceived idea of a products lifespan?

How common is it to receive an old product from the customer after its lifespan?

How common is it that customers purchase a new product while their old is still in working condition?

How does the typical customer of such products look like? Age, living situation, et cetera?
How are orders and deliveries of the products managed and executed?

What is your opinion on the collaboration with Husqvarna? What is good, bad, and where can improvements be made?

Explain remanufacturing. What is your view on the concept just explained?

If you got the opportunity, do you believe you would have the capacity for a remanufacturing process at your dealership?

Do you believe there would exist customers ready to buy a used robotic lawn mower for a slightly lower price?

Under what circumstances would you consider selling remanufactured products?

**NPV**

Cost of setting up production line for robot lawn mower?

Area required by robot lawn mower production line?

Area required by quality assurance activities?

Average price per square meter for a facility in close proximity to Torsvik?

Cost of the tools needed to disassemble and reassemble a robotic lawn mower?

What does the service course cost for Husqvarna to lead?

What is the cost of training a factory worker?

What is the average salary of an operator at Husqvarna in Sweden?

What is the average salary of an operator at Husqvarna’s dealers in Sweden? Alternatively calculated with the cost of service.

Time for manual disassembly and reassembly?

Time for quality assurance activity at factory?

Time for inspection?

Cost of transporting spare parts from supplier to dealers with re-routing performed at main distribution center? (For components like engines, bodies, cutting blades, circuit boards, batteries, et cetera.)

Cost of transporting spare parts from supplier to Torsvik? (as above)

Cost of transporting a robot from main distribution center to dealer?

Cost of transporting a core from dealer to Torsvik?

Internal prices for components; engines, battery, circuit board, wheels, body, cutting blades, bearings, et cetera.