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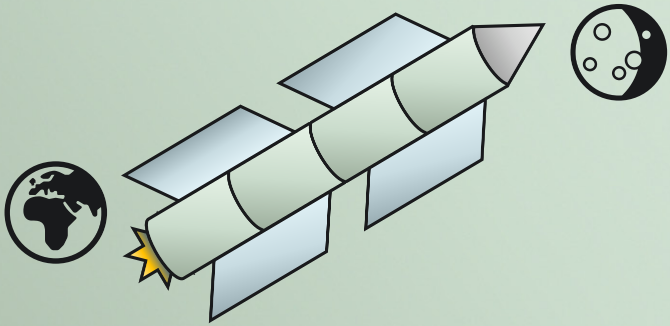
Licentiate Thesis No. 1934

Initiating Original Equipment Manufacturer Remanufacturing

Johan Vogt Duberg



LINKÖPING UNIVERSITY

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INITIATING ORIGINAL EQUIPMENT MANUFACTURER REMANUFACTURING

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Tvivlar man på egen förmåga skapar man ej stora ting

– Anders Zorn

ABSTRACT

Remanufacturing is an industrial process in which a core – a used, discarded, or broken product – is transformed into a product whose specification and condition are new-like. However, to this date, remanufacturing activities on the market are few in comparison to manufacturing. There are several types of remanufacturers; the least common type is the original equipment remanufacturer, an original equipment manufacturer that not only manufactures new products but also remanufactures cores of its own products. The potential for remanufacturing to become a more widely used industrial process for original equipment manufacturers is therefore high. Increased remanufacturing activities can positively contribute to the environment by transforming cores into a new-like condition instead of manufacturing new ones. The contribution comes from a reduction of raw material and energy consumption compared to manufacturing. Therefore, remanufacturing has the potential to decouple environmental impact from economic growth, thus contributing to more sustainable societies. However, assessing the benefits of remanufacturing does not directly correlate to growth within the remanufacturing industry. To encapsulate the environmental, social, and economic benefits of remanufacturing, manufacturers need to be aware of how remanufacturing can be initiated and implemented in practice with positive economic effects. The aim of this licentiate thesis, therefore is, to explore how original equipment manufacturers can initiate profitable remanufacturing.

This research takes a stand in a single case study where the prospect of profitable remanufacturing is studied at an original equipment manufacturer. The applied case study developed knowledge of how remanufacturing could be incorporated into existing operations at an original equipment manufacturer. In parallel, analytical economic assessment models based on cost-benefit analysis were built to measure how well the case company could perform remanufacturing. There were seven primary remanufacturing scenarios developed, ranging from centralised remanufacturing performed by the original equipment manufacturer to decentralised performed at multiple locations using a retail network. Which scenario is preferable depends on, for example, risk-consciousness, cooperation between actors, and volume targets. However, given ideal circumstances, remanufacturing in-house in a centralised scenario was the most beneficial for the original equipment manufacturer since the fewer middle hands and economies of scale also enable lower costs.

The modelled remanufacturing scenarios were based on a set of eight prerequisite factors for original equipment manufacturer remanufacturing that were derived during this research. These factors are divided into essential and supporting prerequisite factors and are illustrated through a framework called *the remanufacturing rocket*. The essential factors highlight fundamental requirements to perform remanufacturing. Should one of the four factors be missing, remanufacturing cannot be successfully initiated. The supporting factors can be neglected to a larger extent but are valuable to enhance the effectiveness and efficiency of the process, such as by streamlined operations, organisational change, or information exchange. Hence, to reach the fullest potential of remanufacturing, both the essential and the supporting factors are needed.

Conclusively, as an answer to the thesis aim, it is proposed to apply the prerequisite factors together with an economic assessment in an iterative manner to investigate the profitability of initiating remanufacturing at original equipment manufacturers. The essential prerequisite factors influence the first iteration of the economic assessment, which then contributes to refinements of how the essential factors should be aligned in an economically preferable way. Once satisfactory, another iterative process could be initiated between the supporting prerequisite factors and the economic assessment. By using the proposed approach, the prospects of profitable remanufacturing could be thoroughly investigated before attempting to initiate a process in practice, thus reducing the number of resources spent in vain. Additionally, the iterative process was integrated into a *five-step approach for initiating remanufacturing (5AFIR)* to guide original equipment manufacturers towards initiating profitable remanufacturing. Through applying this approach, it was shown that the case company could initiate profitable remanufacturing.

Keywords: *Remanufacturing; Circular economy; Value-retention process; Economic assessment; Initiation; Prerequisite.*

SAMMANFATTNING

Återtillverkning är en industriell process där en stomme – en använd, uttjänt, eller trasig produkt – omformas till en produkt vars specifikation och kvalitet motsvarar nyskick. Men återtillverkning utgör endast en liten del av den totala tillverkningsindustrin. Inom återtillverkning finns det flera typer av återtillverkare; den ovanligaste är originaltillverkande återtillverkare, det vill säga, ett tillverkande företag som även återtillverkar sina egna produkter. Genom att det idag är en låg grad av återtillverkning bland originaltillverkare finns det utrymme för att verka för en ökning. Ökade återtillverkningsaktiviteter kan bidra till miljömässiga fördelar genom att nya produkter ersätts med återtillverkade motsvarigheter. Detta bidrag uppstår genom en reduktion av mängden råmaterial och energi som konsumeras i förhållande till nytillverkning. Det finns därför en möjlighet för återtillverkning att bidra till en frikoppling av miljömässig påverkan från ekonomisk tillväxt, vilket i sin tur bidrar till ett mer hållbart samhälle. Fast att endast värdera nyttan av återtillverkning leder inte direkt till en tillväxt inom återtillverkningsindustrin. För att omfamna de miljömässiga, sociala, och ekonomiska nyttor som återtillverkning kan bidra med måste originaltillverkare vara medvetna om hur återtillverkning kan initieras och implementeras i praktiken på ett ekonomiskt lönsamt sätt. Syftet med denna licentiatavhandling är därför att utforska hur originaltillverkare kan initiera lönsam återtillverkning.

Denna forskning utgår från en fallstudie vid en originaltillverkare där möjligheterna för lönsam återtillverkning studeras. Den tillämpade fallstudien bidrog till att utveckla kunskap om hur återtillverkning kan integreras i en originaltillverkares befintliga försörjningskedja. Parallellt med fallstudien utvecklades analytiska ekonomiska värderingsmodeller för att tillhandahålla ett mått på hur väl fallföretaget skulle kunna utföra återtillverkning. I samband med detta utvecklades sju återtillverkningsscenarion. Dessa innefattar centraliserad återtillverkning som utförs av originaltillverkaren och decentraliserad återtillverkning som utförs vid flertalet platser inom ett återförsäljarnätverk. Vilket scenario som är mest fördelaktigt beror exempelvis på riskmedvetenhet, samarbete mellan aktörer, och tillverkningsvolym. Men givet ideala förhållanden visades det att centraliserad återtillverkning är mest fördelaktigt för originaltillverkaren, eftersom färre mellanhänder och skalfördelar möjliggör lägre kostnader.

De sju återtillverkningsscenariona baserades på åtta förutsättningsfaktorer som utvecklades för att forma krav för hur originaltillverkare kan initiera återtillverkning. Dessa faktorer delas upp i grundläggande och stödjande förutsättningsfaktorer, och de bygger tillsammans upp ett ramverk benämnt *återtillverkningsraketen*. De

grundläggande faktorerna lyfter fram elementära krav vid utförandet av återtillverkning. Om en av de fyra grundläggande faktorerna skulle saknas kan återtillverkning inte utföras på ett framgångsrikt sätt. De stödjande faktorerna kan i större utsträckning utelämnas, men de är av värde för att förbättra återtillverkningseffektiviteten genom exempelvis bekymmersfritt utförande av processer, organisationsförändringar, eller informationsutbyten. Därigenom, för att nå den fulla potentialen av återtillverkning, behövs både de grundläggande och de stödjande förutsättningsfaktorerna.

Slutligen, som ett svar på avhandlingens syfte, föreslås det att tillämpa de framtagna förutsättningsfaktorerna tillsammans med en ekonomisk värdering genom att iterativt undersöka möjligheterna för hur återtillverkning kan initieras för originaltillverkare. De grundläggande förutsättningsfaktorerna influerar upplägget för den första iterationen av den ekonomiska värderingen, vilken i sin tur nyttjas för att förfina hur de grundläggande faktorerna kan läggas samman på ett ekonomiskt fördelaktigt sätt. När en godtagbar nivå uppnåtts kan ytterligare en iterativ process utföras mellan de stödjande förutsättningsfaktorerna och den ekonomiska värderingen. Genom att tillämpa det föreslagna tillvägagångssättet kan möjligheterna för återtillverkning undersökas på en detaljerad nivå innan initieringsförsök i praktiken, och således kan mängden resurser reduceras som annars hade konsumerats förgäves. Utöver detta integrerades det iterativa tillvägagångssättet med en *femstegsansats för initiering av återtillverkning (5AFIR)* för att vägleda originaltillverkare mot lönsam initiering av återtillverkning. Genom att tillämpa denna ansats visades det att fallföretaget skulle kunna initiera lönsam återtillverkning.

Nyckelord: Återtillverkning; Cirkulär ekonomi; Värdebevarande process; Ekonomisk värdering; Initiering; Förutsättning.

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Jag har nu nått en punkt i mitt arbete som innebär att jag ska sammanställa min forskning och redovisa det i form av en licentiatavhandling. Det är den avhandlingen som du har till hands i just denna stund. Detta är ett delarbete i något större, men ack ändå ett viktigt steg att utföra för att underlätta spridningen av de forskningsresultat som har uppnåtts. Forskningen måste trots allt komma till någon nytta, annars är såväl tid som pengar bortkastat; givet att man bortser från en personlig vinning såklart.

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[1] The VINNOVA *Challenge-driven innovation* initiative and the project ElevatoRe: *Elevate remanufacturing to EEE manufacturers' strategy towards circular economy (dnr: 2018-00330).*

[2] The Swedish Energy Agency through the "Remometer" project, dnr 2019-021532, within the strategic innovation program RE:Source.

[3] The Mistra REES (Resource Efficient and Effective Solutions) program (No. 2014/16), funded by Mistra (The Swedish Foundation for Strategic Environmental Research).

APPENDED PAPERS

PAPER I Vogt Duberg, J., Johansson, G., Sundin, E., Kurilova-Palisaitiene, J., 2020. Prerequisite factors for original equipment manufacturer remanufacturing. Journal of Cleaner Production. 270, 122309.
The ideation of the manuscript was conducted by all authors in a collaborative manner. Johan Vogt Duberg and Gustav Johansson together conducted the underlying case study and wrote the first draft of the paper. The revision of the paper was handled by Johan Vogt Duberg, who rewrote several sections.

PAPER II Vogt Duberg, J., Johansson, G., Sundin, E., Tang, O., 2020. Economic evaluation of potential locations for remanufacturing in an extended supply chain – a case study on robotic lawn mowers, in: Procedia CIRP. Presented at the 27th CIRP Life Cycle Engineering (LCE) Conference, Grenoble, France, pp. 14–18.
Johan Vogt Duberg planned and conducted all steps of the study together with Gustav Johansson. Together, they wrote the manuscript.

PAPER III Vogt Duberg, J., Kurilova-Palisaitiene, J., Sundin, E., 2021. Assessing an EEE manufacturer's economic benefit with remanufacturing, in: Procedia CIRP. Presented at the 28th CIRP Life Cycle Engineering (LCE) Conference, Jaipur, India, pp. 103–108.
Johan Vogt Duberg planned the early stages of the study together with Jelena Kurilova-Palisaitiene. Choice of research method, development of the model, data collection, data curation, analysis, and authoring of the manuscript were conducted by Johan Vogt Duberg.

OTHER PUBLICATIONS

i. Kurilova-Palisaitiene, J., Vogt Duberg, J., Johansson, G., Sundin, E., 2020. How an OEM Can Become Circular with Remanufacturing: The Case of Robotic Lawn Mowers, in: Proceedings of the 9th Swedish Production Symposium (SPS), Advances in Transdisciplinary Engineering. Jönköping, Sweden, pp. 261–272.

ii. Chari, A., Vogt Duberg, J., Lindahl, E., Stahre, J., Despeisse, M., Sundin, E., Johansson, B., Wiktorsson, M., 2021. Swedish Manufacturing Practices Towards a Sustainability Transition in Industry 4.0: A Resilience Perspective, in: Volume 1: Additive Manufacturing; Advanced Materials Manufacturing; Biomanufacturing; Life Cycle Engineering; Manufacturing Equipment and Automation. Presented at the ASME 2021 16th International Manufacturing Science and Engineering Conference, American Society of Mechanical Engineers, Virtual, Online, V001T04A002.

Reports

Chari, A., Vogt Duberg, J., Lindahl, E., William-Olsson, P., Sundin, E., Wiktorsson, M., Johansson, B., Stahre, J., Warrol, C., 2021. Sustainability in Produktion2030: Sustainability and Circular Economy Actions within the Project Portfolio of the Produktion2030 Strategic Innovation Programme. Produktion2030.

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ABBREVIATIONS AND TERMINOLOGY

CE	CIRCULAR ECONOMY "A regenerative system in which resource input and waste, emission, and energy leakage are minimised by slowing, closing, and narrowing material and energy loops" (Geissdoerfer et al., 2017).
CLSC	CLOSED-LOOP SUPPLY CHAIN A supply chain consisting of both forward and reverse logistics channels. Commonly also incorporating remanufacturing (Guide and Van Wassenhove, 2009).
Core	A used, discarded, or broken product aimed for remanufacturing (Lund, 1984).
EoL	END OF LIFE A state where a product is no longer of use and cannot undergo value-retention processes (Nasr and Russel, 2018).
EoU	END OF USE A state where a product is no longer of use and can undergo value-retention processes (Nasr and Russel, 2018).
NPV	NET PRESENT VALUE A method to discount future cash flows to present values (Anupindi et al., 2012).
OEM	ORIGINAL EQUIPMENT MANUFACTURER A manufacturer which designs and manufactures products (Lund, 1984).
PSS	PRODUCT-SERVICE SYSTEM A business model where access to products and services are sold instead of product ownerships (Tukker and Tischner, 2006).
Remanufacturing	An industrial process in which a core is transformed into a product whose specification and condition are like new (Lund, 1984).
VRP	VALUE-RETENTION PROCESS A process that retains value after EoU. For example, remanufacturing, refurbishment, reuse, and repair (Nasr and Russel, 2018).

1 INTRODUCTION

The first chapter of this licentiate thesis provides an introduction and a background to the research area on remanufacturing, why the process should be performed, and which challenges need to be overcome to enable wider use of remanufacturing activities. The chapter also shapes the aim of the thesis and the processed research questions, hence, creating the scientific foundation of the conducted research. Finally, the delimitations and thesis outline are presented.

1.1 BACKGROUND

The idea of replacing linear resource flows with more circular ones has been raised on the societal and academic agenda through the fear of the irreversible impact on the climate (IPCC, 2021), but also through comprehensive dissemination of potential solutions; see (EMF, 2015). As the need for sustainable development is continuously increasing, the research on value-retention processes (VRPs) can take a position to close the resource loop and contribute to more sustainable and environmentally benign industrial processes (Nasr and Russel, 2018). Remanufacturing is one such VRP where used, discarded, or broken products (cores) are restored to a new-like condition (Lund, 1984). As such, through remanufacturing, one piece in a regenerative system, whose inputs and outputs are retained through use cycles, is laid (EMF, 2013; Geissdoerfer et al., 2017), enabling the decoupling of economic growth from environmental impact (Gilli et al., 2017). Hence, society can continue to prosper (Garetti and Taisch, 2012) with the inclusion of sustainable norms (Elkington, 1998). This is the case since remanufacturing has the ability to reduce the emission of carbon dioxide (CO_2) and the consumption of energy and material compared to manufacturing (Kerr and Ryan, 2001; Lindahl et al., 2006; Sundin and Lee, 2011).

However, remanufacturing is inherently complex due to many uncertainties (Lundmark et al., 2009), which makes it difficult to reach its positive effects. Commonly, there are uncertainties related to the availability and condition of cores (Kamper et al., 2019; Sundin and Dunbäck, 2013), making remanufacturing difficult to plan and develop. Further challenges are legislative restrictions (Lindkvist Haziri et al., 2019; Wei et al., 2015a), market acceptance (Guidat et al., 2015), lack of internal communication (Lindkvist Haziri et al., 2019), and lack of spare parts (Kurilova-Palisaitiene et al., 2018), thus setting high requirements on realisations of remanufacturing operations.

Furthermore, when initiating remanufacturing, resource flows are transformed from linear to circular (Guide and Van Wassenhove, 2009). To facilitate the transformation, both materials and products should be redesigned for the new circumstances, as well as developing new business models, implementing diverse reverse networks, and deriving suitable policy conditions (Planing, 2015). These are the building blocks of a circular economy (CE), and they are critical for a successful initiation of remanufacturing. The success of remanufacturing is determined based on how efficient products undergo the product life cycle stages, as seen in see Figure 1. For example, early product design decisions influence environmental impact throughout the product life cycle (Lindahl and Sundin, 2013). It is, therefore, necessary, already in the design stage, to plan for how products are remanufactured as the system becomes more complicated further down the process (Hatcher et al., 2011; Sundin et al., 2009).

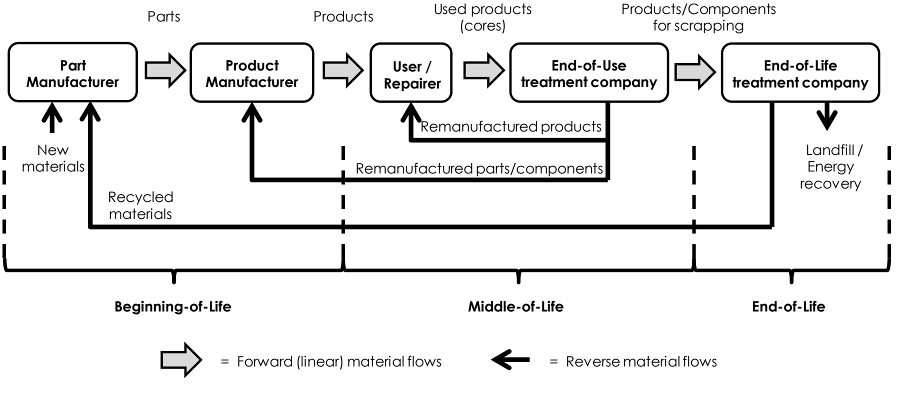

Figure 1. A product life cycle of a product that undergoes remanufacturing (Johansson et al., 2019).

In comparison to the manufacturing sector, remanufacturing corresponds to 1.9% in Europe (Parker et al., 2015) and 2% in the United States of America (USITC, 2012). Viewing the American and Canadian remanufacturing market, almost 4% of all remanufacturers were original equipment manufacturers (OEMs) (Lund, 2012). Other types of remanufacturers are independent or contracted (Lund, 1984), as shown in Table 1. These percentages are on the low-end, meaning that, to encapsulate the benefits that remanufacturing can bring to society, the remanufacturing know-how should be disseminated to promote OEM remanufacturing initiations. Such a dissemination could not only increase the size of the remanufacturing market on an aggregated level but also target OEMs specifically. Even though the number of OEM remanufacturers has been reported as low (Lund, 2012), the potential for OEMs to perform remanufacturing is high due to their position to influence all phases of manufacturing from design to final assembly, meaning that they are capable of adapting their products for remanufacturing (Hatcher et al., 2013).

Table 1. Three remanufacturing types and their corresponding definitions. Based on Lund (1984).

Remanufacturer type	**Principle**
OEM remanufacturer	… performs remanufacturing of its own products.
Contracted remanufacturer	… performs remanufacturing on behalf of another actor.
Independent remanufacturer	… performs remanufacturing independently of an OEM without any collaboration or contract.

The promotion and dissemination of remanufacturing benefits could involve the economic benefits of practitioners (Linton, 2008; Parker et al., 2015; Sundin et al., 2016). The type of remanufacturer affects how information is transferred between the remanufacturer, the OEM, and the sales actors (Kurilova-Palisaitiene et al., 2015), as well as how knowledge is shared between the actors and how collaborations are arranged (Lund, 1984; Sundin et al., 2000). Each of these faces various challenges, but once conquered, remanufacturing can contribute to, for example, finding new customer segments (Abbey et al., 2015b), allowing premium brands to compete in low-price markets (Atasu et al., 2008a), enhancing communication channels between users and producers (Lund, 1984), protecting aftermarkets (Seitz and Peattie, 2004), and improving brand equity (Toffel, 2004). By considering any or all of these as linked to business drivers for remanufacturing – profit, environment, and policy – remanufacturing can be of interest for companies (Östlin et al., 2008a).

To grasp the benefits remanufacturing can bring, there are, therefore, needs for approaches that highlight case-specific benefits for individual companies, that is, approaches that stimulate the growth of the remanufacturing industry. An OEM focus is of interest, partly since they are in the minority in terms of remanufacturing actors (Lund, 2012) and partly since they tend to have the capability to influence the design of products and possess product-specific knowledge (Hatcher et al., 2013). By assessing the profitability of initiating remanufacturing, OEMs can gain insights for confident decision-making on whether remanufacturing is worthwhile to initiate.

1.2 AIM AND RESEARCH QUESTIONS

OEMs have the power to enable circular processes through remanufacturing since they typically influence both design and manufacturing decisions (Hatcher et al., 2013). However, original equipment manufacturer remanufacturing is uncommon in remanufacturing practice; see Lund (2012) and Sundin et al. (2016). Hence, mapping and understanding how OEMs can initiate profitable remanufacturing are worth investigating. Therefore:

The aim of this thesis is to explore how original equipment manufacturers can initiate profitable remanufacturing.

When building the foundation of remanufacturing, it is necessary to understand what building blocks are needed (Barquet et al., 2013). Otherwise, remanufacturing could be unsuccessfully set up, neither reaching quality nor profitability targets. Related to this is the remanufacturing know-how. With the knowledge, the link between all building blocks could be visible, thus making it possible to confidently take the step towards a remanufacturing initiation. This leads to the first research question:

RQ1. What prerequisites are needed when initiating original equipment manufacturer remanufacturing?

Once the remanufacturing prerequisites have been identified and the foundation has been laid, there is a foundation to rely on when initiating remanufacturing. However, in order to stay profitable, companies must be competitive (Gallo et al., 2012; Porter, 1998). It is, therefore, unlikely that OEMs would actively pursue and initiate remanufacturing if it were deemed unprofitable. As such, it is of interest to investigate the economic assessment of initiating remanufacturing as the second research question:

RQ2. How can an initiation of original equipment manufacturer remanufacturing be assessed from an economic perspective?

When finding answers to these research questions, OEMs could gain insights that enable confident decision-making on whether remanufacturing is worth further investigation or even a direct initiation.

1.3 Delimitations

To narrow down the scope of the study, the subsequent delimitations have been set in this research study.

- The research has been conducted from the perspective of OEMs without prior remanufacturing experience.
- The considered products are electronic and electrical equipment.
- The remanufacturing process considers products. There is no focus on remanufacturing of individual components.
- The environmental and social perspectives of sustainability have not been considered in the assessments.
- The economic assessment focuses on evaluating remanufacturing cash flows without comparison with manufacturing. To compare remanufactured and new products, only the sales price is considered.
- The remanufacturing prerequisites and economic assessment neglect the influence of legislations and policies or similar considerations.

2 RESEARCH METHODOLOGY

The second chapter of this licentiate thesis presents the research methodology. First, the fundamental research design is described. This is followed by the procedures of the two research methods – single case study and modelling – and the motivations of the selected methods. Third, data collection methods are covered similarly. Finally, the research study is covered from the validity and reliability perspectives.

2.1 RESEARCH DESIGN

The presented research is built upon an approach of satisfying two different worldviews: one of enterprises with a focus on *competitiveness* and *profitability*, and the one of science, where there is an ambition to add to the cumulative knowledge in the present research paradigm. The research conducted is founded upon a research interest in understanding how to evaluate whether remanufacturing is worth initiating for OEMs or not. To increase the understanding of remanufacturing and conduct the research, interest needed to be lit within industry by disseminating the benefits remanufacturing could imply for the OEM.

To ignite the interest of industry, several OEMs with products perceived as suitable for remanufacturing were contacted. One electronic and electrical equipment OEM showed interest and wanted to understand whether they could perform profitable remanufacturing. The industry case was used to ground the research study in empirical data as well as to study how an OEM's prospects for initiating profitable remanufacturing could be evaluated with economic assessment methods. These assessment methods could exemplify the evidence of what OEMs require for decision-making and advance the scientific area of assessing remanufacturing initiations.

The study's unit of analysis – the case – is the case company's prospects of initiating profitable remanufacturing. The case company provided data, product-specific knowledge, and validations, while the researchers documented and analysed the remanufacturing prospects and scenarios. In parallel, models were built to mimic the economic performance of remanufacturing. These two research methods, the case study and modelling, are further elaborated on in the following subchapters. There, the applied method and the method theory have been interwoven. The selected theory relates to practices that have been applied during the research and should therefore be read as such. Table 2 shows where the research methods and the literature reviews have been used for the three appended papers and their contribution to answering the research questions.

Table 2. The research methods and the literature review used to answer the two research questions and their contributions in the appended papers. A ● indicates a major contribution, while a ○ indicates a minor contribution.

	Literature review	Modelling	Single case study	Paper No.
RQ1.	●		●	I
RQ2.	○	●	●	II, III

The research process started with a literature review, which framed the basis of the theoretical foundation and pinpointed research gaps the research questions could target; see Figure 2. Initially, the literature review was the primary data collection method within the single case study and modelling. The literature review structured the basis of Paper I early on. As the research progressed, the need for new literature searches became saturated which meant that empirical data from interviews took a more prominent role. The transition from theoretical to empirical data indicated a shift in the research structure, enabling the development of the models for Papers II and III.

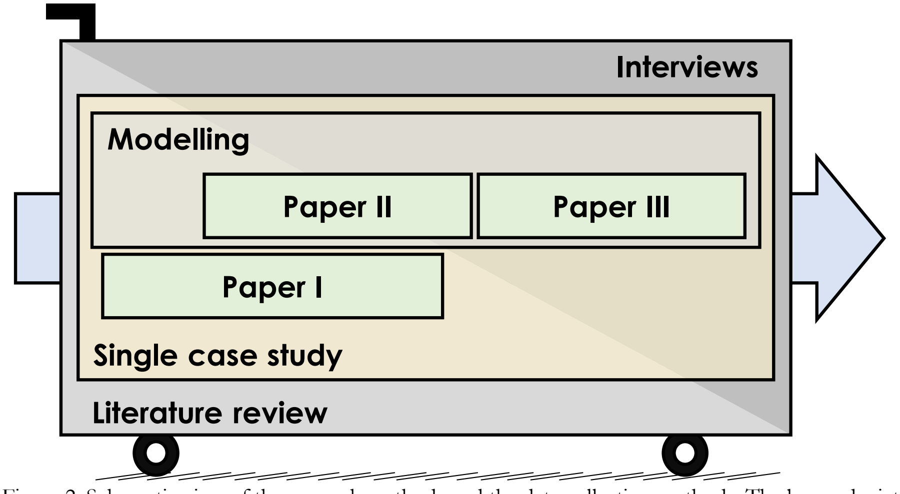

Figure 2. Schematic view of the research methods and the data collection methods. The boxes depict when the methods were applied in the study as well as their use in the appended papers.

2.2 CASE STUDY METHODOLOGY

What defines a case study is a matter of perception and has changed over the years (cf. Benbasat et al., 1987; George and Bennett, 2005; Merriam, 1994; Yin, 2018). Nonetheless, when comparing the two definitions by Yin (2018) and Leonard-Barton (1990), it is emphasised that the study of a past or current phenomenon in its own context creates the basis for a case study. On top of that, a set of data collection methods is required. Case studies can also be conducted in real time to study how a phenomenon progresses (Säfsten and Gustavsson, 2020). In this thesis, the real-time aspect corresponds to the analysis of the remanufacturing profitability.

The single case study as the primary research method was selected thanks to its capabilities to contribute to an in-depth investigation of a phenomenon, that is, the remanufacturing profitability, as well as its capability to build new theory; see Yin (2018) and Ketokivi and Choi (2014). Case study research was also suitable for answering the proposed *how* and *what* questions of this thesis (cf. George and Bennett, 2005; Voss et al., 2016; Yin, 2018). From the explorative point of view, the research method fits well as a remanufacturing initiation must be assessed and explored. As such, the research objective is processed by adding to the cumulative knowledge of the research paradigm by building theory and making scientific contributions, which utilises the theory testing and refinement abilities of case studies; cf. Voss et al. (2016).

Case study research also provides strong conceptual validity by creating a credible interpretation of an area that stimulates further research, as well as enables exploration of causal mechanics (George and Bennett, 2005). These aspects were considered important when designing the study since previous research on how OEMs without prior remanufacturing experience can initiate remanufacturing is limited. Therefore, considering the in-depth and reliable exploration capabilities of case study research, the method was selected and viewed as suitable for thorough coverage of a remanufacturing initiation. However, the trade-off of single case studies means that the study is likely to have a limited capability to provide generalisable results (cf. Voss et al., 2016). On the other hand, single case studies are powerful because they enable a thorough and deep processing of the case, thus leading to the effective creation of knowledge (Voss et al., 2016; Yin, 2018). This further emphasises case study research as suitable in this research study.

The case study research was conducted primarily by collecting and processing data from the case company of its current operations as well as relevant data for remanufacturing based on a theoretical understanding. See Subchapter 2.4 for the data collection methods used.

2.2.1 CASE COMPANY DESCRIPTION

For the single case study, an electronic and electrical equipment OEM of premium classed robotic lawn mowers was selected. The case company is Swedish and acting on a global market. In this study, its supply chain and business activities on the Swedish market were within the scope. There, the case company has an established retail network consisting of over 300 retailers. These retailers purchase products from the case company and then sell these to the end customers. The retailers are also responsible for repair and service activities on the market, meaning that they have repair workshops specialised in handling the case company's products. To be classed as an authorised retailer, the retailers must meet certain requirements, such as following service and repair guidelines, using genuine spare parts, and promoting the sales of the case company's products.

The primary applied business model is traditional sales, where the ownership of the product is transferred to the end customer at purchase. Therefore, neither the case company nor the retailers can track or control products past the point of sales. This results in a difficulty to receive data on product deterioration and how the products are handled during the use phase. For distribution, the case company has a local distribution centre from which spare parts and new products are sourced to retailers on the market. The distribution centre is supplied by a manufacturing plant positioned abroad. At the start of the case study, the case company had no previous experience in remanufacturing.

2.3 MODELLING METHODOLOGY

The modelling method of this research was selected as a method to complement the case study method. Since remanufacturing does not exist at the case company, a model was needed to set the findings into perspective and assess whether they were reasonable from an economic perspective when put into context. In this study, a model is viewed as a tool that mimics reality by describing its behaviour given a set of inputs. This is similar to how Ljung and Glad (2004) described models. For this purpose, a model was built to describe whether remanufacturing could be profitable at the case company.

There are many different types of models. In this thesis, there was a focus on analytical economic models. The design choices were to keep the model on a low complexity level to easily anticipate its behaviour and interpret its output. As such, the analytical model is a rather simplified version of reality with a focus on the cost structure of remanufacturing at the case company. Such simplified models tend to be easy to solve but lack the ability to describe complex relations between variables (Bertrand and Fransoo, 2016). Since remanufacturing has a natural occurrence of uncertainty (Lundmark et al., 2009; Sakao and Sundin, 2019) and there is a portion of uncertainty in modelling a new type of process, it was considered a fair trade-off to make. The analytical economic model is deterministic but is complemented with a sensitivity analysis to extend its robustness.

A sensitivity analysis considers the uncertainty of a model's output (Saltelli, 2002). One example is a break-even analysis, which starts in a scenario of zero profitability, and then inputs could be altered to identify the robustness of a given scenario (Dean, 1948). In this study, the modelling approach was twofold. Firstly, a rough net present value (NPV) model was built. It had the purpose of screening various remanufacturing alternatives from an investment perspective. Alternatives that were deemed as promising were selected for further investigation. Secondly, a break-even analysis was chosen to view the throughput rate on a detailed level, with the reason, as described by Patrick (1958), that it is suitable to scale volume-based parameters.

2.3.1 NET PRESENT VALUE MODEL

NPV is built upon the principle of discounting future cash flows to the present value to comprehend, for example, the value of an investment and its total gain, given that value is time-dependent (Anupindi et al., 2012); see Figure 3. Generally, a positive NPV indicates that the task is worth proceeding with. However, the value should always be set into perspective with other alternative tasks to determine the true value of investing a monetary value (Feldstein, 1964). The discount rate can handle risk adjustment (Pierru and Feuillet-Midrier, 2002), but, in Paper II, the discount rate was set to a value to correspond to the return on investment requirements of other investments at the case company. As such, given a positive NPV, the case company could internally compare the remanufacturing scenario with other investments. However, the risk adjustment capabilities of the discount rate were not fully embraced in this research study. Instead, the complementary sensitivity analysis handled that aspect.

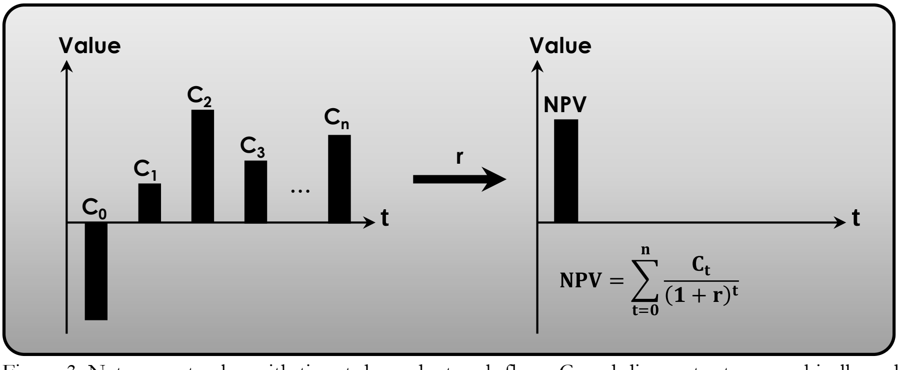

Figure 3. Net present value with time t dependent cash flows C_t and discount rate r, graphically and mathematically.

Paper II covered the early stages of the remanufacturing study by applying the NPV model when assessing the profitability of initiating remanufacturing at several locations within the existing supply chain of the case company. The modelled cash flow variables were based on expected costs and revenues of the remanufacturing system at the case company. Subchapter 3.1 describes the underlying theoretical remanufacturing foundation of the model, while Chapter 5 covers the outputs. Since the cash flow variables are expected future values without reliance on historical data, there is a level of uncertainty in the model outputs. This was handled in two ways. Firstly, all scenarios were based on estimates from the same sources and, as far as possible, the same values, meaning that inaccuracies would affect the scenarios similarly, thus preserving the order of preferability. Secondly, a sensitivity analysis of the NPV variables was conducted. Here, every variable was adjusted within a specified range, and the resulting NPV output was noted. It was this approach that motivated the further sensitivity analysis based on break-even; see Subchapter 2.3.2.

2.3.2 Break-even sensitivity model

In the consecutive part of the research study, as covered in Paper III, the model was further developed with more detailed scenarios. The primary purpose of the extended model was to identify at what remanufacturing throughput rate remanufacturing was perceived as worthwhile to perform given a set of circumstances. The further study was conducted from a sensitivity analysis perspective based on break-even analysis by developing scenarios and adjusting input values. As Borgonovo and Plischke (2016) described, a sensitivity analysis enables the ranking of scenarios based on the influence of inputs. Therefore, scenarios were built to identify what influences the profitability of remanufacturing at the case company.

A break-even analysis is built upon a principle of identifying when a scenario reaches a state where the total costs and revenues are equal (Dean, 1948). From that state, a further analysis can be conducted to specify a margin of safety, that is, a unit past the break-even point. In this thesis, the developed model provided a target volume past the break-even point. At the target volume, the fixed cost share of the total cost had reached a perceived low level, meaning that the profit margin per product was near its maximum value; see Figure 4. Seven scenarios were developed by primarily tweaking the responsible actors for core acquisition, sales, and the remanufacturing process. As such, these scenarios showcased both decentralised and centralised remanufacturing as well as various collaborations between the case company – the OEM – and its retail network and how these relate to the benefits of the case company; see Chapter 5 for further details.

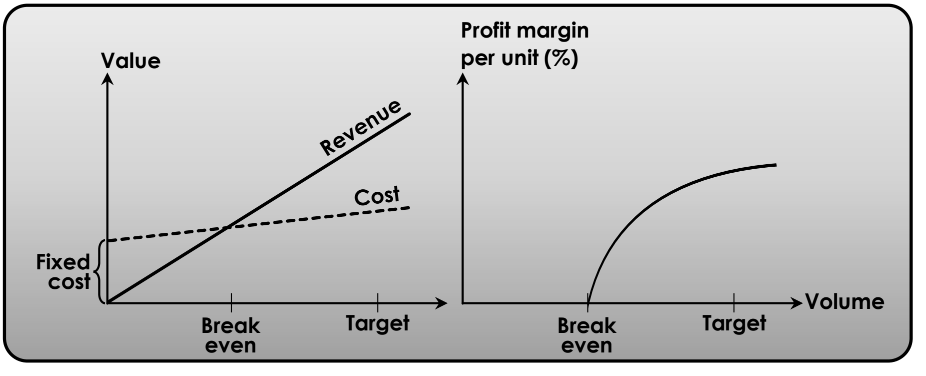

Figure 4. Break-even point and the volume where the profit margin per product has reached the target value.

2.4 DATA COLLECTION

Two types of data collection methods were used throughout the case study, namely, the literature review and interviews. Multiple methods were selected for several purposes: triangulation, to collect both theoretical and empirical data, and to broaden the range of data available. Triangulation, which strengthens data reliability (Voss et al., 2016; Yin, 2018), was integral as the understandings and perceptions of the interviewees varied, which, in turn, influenced the quality of the collected primary data. Literature reviews were conducted throughout the research study to create the theoretical foundations of Papers I, II, and III. The interviews acted as the transfer of information of case specifics into a data set that was interwoven with the theoretical basis for modelling purposes and execution of the case study.

2.4.1 Literature review

The appended papers are based on the same initial literature review search on scientific literature. For specific needs, additional minor searches were conducted. As literature reviews navigate previous research and identify research gaps (Karlsson, 2016; Säfsten and Gustavsson, 2020), the method was applied to justify the research for Papers I, II, and III, and derive the research questions of this thesis. The undertaken literature review has been used as a complement to empirical findings. For example, Paper I is founded thoroughly in theory derived from the literature review since the findings are based on manufacturing and remanufacturing theory and exemplified through the case study of how it could be interpreted in a practical scenario; see Chapter 4 for further information. In comparison, Papers II and III applied the literature review to design the structure of the remanufacturing scenarios and to accurately model them analytically.

Remanufacturing has been the common denominator for all literature searches and has been applied together with the search terms *manufacturing strategy*, *manufacturing capability*, *product development*, *design*, *supply chain*, *facility*, *redistribution*, *production system*, *reverse logistics*, *systems*, *plant, core acquisition*, *sales* and *management* in the search engines Scopus, Emerald Insight, Business Source Premier, and Google Scholar. These searches were not systematic; instead, they aimed at exploring the research area broadly. In addition, both forward and backward snowballing have been applied to broaden the search further and link the cumulative scientific progress to a common definition of remanufacturing and its adjacent activities. The forward snowballing was conducted using the citing function of Google Scholar. A snowballing approach enables the linkage of literature by viewing the preceding and succeeding referred literature of a selected source (Wohlin, 2014). Since snowballing also provides a time-efficient alternative to traditional literature searches (Wohlin, 2016), the approach was in this thesis more preferred than a systematic literature review.

The literature review was also used to develop the interview topics and questions when collecting data related to the case company. The literature was processed in a thematic analysis, in which areas of critical relevance to remanufacturing were created. These areas were, for example, *core acquisition*, *reprocessing*, and *sales*, as well as areas with relevance to current manufacturing practices and product characteristics, such as *supply chains*, *production systems*, *market*, and *electronic and electrical equipment*. Similarly, a thematic analysis was also the basis when identifying prerequisite factors for Paper I and the basis for developing the models for Papers II and III.

2.4.2 INTERVIEWS

During the case study, interviews were used to collect data on the current OEM operations and remanufacturing-relevant aspects. In total, 41 unique individuals were interviewed, as shown in Table 3. During some sessions, multiple individuals were present. The interviews conducted were either semi-structured with prepared questions or unstructured, where only the interview topic was known beforehand. This method was chosen since the interviewees and case study could be targeted exploratively, thus enabling the collection of data that the interviewer otherwise could have neglected due to bias or lack of insight (cf. Brinkmann and Kvale, 2015; Voss et al., 2016). Initially, the interviews were more on the structured side, but as the study progressed, more were of an unstructured nature. The reason being was that the semi-structured interviews created the basis of the data, while the unstructured interviews filled in the missing gaps and extended the data set.

On many occasions, several interviewees were present by the initiative of the case company representatives. These interviews enabled the interviewees to have a discussion related to the interview topic. The interviewee with the most insight into an area often provided the main response. There were also three group interviews conducted to determine critical remanufacturing aspects, such as product selection, product classification, and pricing schemes. These sessions were unstructured with one prepared topic to decide on since it, as Frey and Fontana (1991) described, enabled in-depth processing with multiple perspectives of the investigated topic. The role of the researcher was mostly passive by primarily following the discussion and providing a theoretical perspective of the topic, according to the recommendations of Bryman (2018).

Table 3. The number of interviews with each interviewee. All interviewees except the remanufacturers and retailers were case company representatives.

Interviewee	#	Interviewee	#
After sales manager A	10	Product manager A	2
After sales manager B	3	Product manager B	1
After sales manager C	2	Product manager C	1
Business developer A	4	Project manager	5
Business developer B	2	Regional manager A	3
Business developer C	2	Regional manager B	1
Business developer D	2	Repair workshop manager	2
Business developer E	1	Research and development manager	5
Business developer F	1	Retail development manager	1
Controller A	1	Retailer A	4
Controller B	1	Retailer B	4
Controller C	1	Retailer C	3
Finance manager	1	Retailer D	2
Independent remanufacturer	1	Retailer E	1
Lean manager	1	Retailer F	1
Logistics director	2	Retailer manager, OEM	4
Manufacturing manager	1	Spare parts specialist A	3
OEM remanufacturer A	1	Spare parts specialist B	2
OEM remanufacturer B	1	Supply chain manager	1
Pricing specialist A	2	Tax manager	1
Pricing specialist B	1		
		Total interviews	**88**

Most of the sessions were performed in either a voice or video conference call. When possible, audio was recorded to ensure no missing information when transcribing the notes taken during the interview sessions. Non-recorded sessions were due to unsuitable circumstances, for example, during more spontaneous sessions labelled as meetings instead of interviews and where it was perceived that asking for permission to record would make the interviewee hesitant to share information, such as when collecting data with high confidentiality. During the first 23 sessions, two researchers were present, one responsible for interviewing while the other for notetaking. Throughout the remaining sessions, the collaboration between the case company and the researchers intensified, meaning access to sensitive data and confidential subjects. As a single interviewer could make the interviewee less reductive (Säfsten and Gustavsson, 2020), the method was perceived as preferable during a higher level of confidentiality. Furthermore, to maintain a high level of trust (DiCicco-Bloom and Crabtree, 2006) and enable access to confidential information, these sessions were not recorded.

In a similar manner to the thematic analysis of the literature data, the interview data was interpreted and processed into themes that described current processes and remanufacturing prospects. All processed interview data was continuously shared with the case company throughout the study to ensure reliability by eliminating inaccuracies due to misinterpretations. Thereafter, all data sets were processed to create the scenarios the models were built upon. The literature data provided the remanufacturing perspective, while the interview data provided the case-specific circumstances.

2.5 VALIDITY AND RELIABILITY

Confirming research results is an important step in validating scientific contributions (Yin, 2018). It is also a relevant question in research ethics where replicability has a major role (Vetenskapsrådet, 2017). During the research study, the data and findings have been validated continuously. In the following sections, the eight validation techniques as recommended by Creswell (2014) are covered; see Table 4.

Table 4. Validation techniques and how they are applied. Based on Creswell (2014).

Validation techniques	Principle
Triangulation	Using multiple data sources to create a solid justification.
Member checking	Presenting findings to participants to ensure accurate descriptions.
Rich description of findings	Describing the research setting and findings from multiple perspectives.
Clarify bias	Sharing the background of the researcher and providing a narrative self-reflection on how this affects the research.
Present negative results or discrepant information	Presenting contradictory evidence, such as negative results or discrepant information for a more realistic view.
Prolong research field time	Conducting long studies enables an in-depth understanding of a case and more accurate findings.
Peer debriefing	Inviting peers to review the methodological approach and findings.
External audit	Inviting external persons to review the methodological approach and findings.

Based on these validation techniques, six were applied and are described below. The two that were not, *clarify bias* and *present negative results or discrepant information,* have not been fully acknowledged during the research study. For the former, personal information about the researcher has not been enclosed here, but publicly accessible information available online that could provide a view of the individual. For the latter, there were no such results or information to enclose in this research study.

1. **Triangulation.** During the interview phase, the same questions were asked to several interviewees, meaning that there were always several inputs for every

data point. Triangulation was also directly achieved in interviews with multiple participants, as group interviews may provide highly reliable data (Frey and Fontana, 1991). A reality check of the interview data was also conducted when interpreting it in relation to theory based on the conducted literature review. To prevent biases, the case study and the model building were conducted in close collaboration with the case company. There were always multiple persons involved in every step, meaning that subjective preferability was reduced as far as possible.

2. **Member checking.** All data used in the study was subject to review by the case company. Firstly, the transcribed interview data was sent to the interviewees. Secondly, all material and results were sent to the case company for review. The company confirmed that the collected data was within reasonable levels. Furthermore, the economic assessment results for decentralised scenarios were confirmed to be reasonable by highly experienced repair managers at two retailers. From this, parallels could be drawn to the centralised scenarios as well.
3. **Rich description of findings.** When reporting the findings, as seen in Chapter 5 and forward, there was an attempt to be transparent in how the economic assessment was conducted, as well as regarding the reasoning beyond the values themselves.
4. **Prolong research field time.** The research study with the case company was carried out over 1.5 years. Beyond that, contact was kept for another year. This ensured that the results had time to mature within the company before the writing of this thesis. Furthermore, the research team had support from highly experienced researchers within the area of remanufacturing. Their views on the topic, approach, and results were viewed as valuable in ensuring that the data and results were accurate.
5. **Peer debriefing.** This was linked to the research duration, as mentioned in the description of *prolong research field time*. The highly experienced researchers of the research team were continuously checking that the research study was conducted reasonably and that the findings made sense from their perspective. Their roles were rather to supervise the progress of the research than to conduct it.
6. **External audit.** In the initial stages of the research study, two external individuals were recruited to review the research method and preliminary results. At the final stage of the research study, Papers II and III were also presented at two separate conferences on life cycle engineering, where the content of the research study was discussed and reviewed. Paper I also underwent a thorough reviewing process at a highly ranked academic journal by two external reviewers.

Model validation. The NPV and break-even models have not been fully validated, since the remanufacturing process has yet to be fully implemented. However, all parts of the model have undergone reasonability checks and match the expectations of both case company representatives and the involved researchers. Two retailers also confirmed that the results were reasonable from their point of view. If the remanufacturing process is initiated in practice, the model could be validated, but then, the main purpose of the model – assessing the profitability of initiating remanufacturing – is no longer required. Every decision during the modelling and its effect on the output processes has been carefully considered. However, due to simplifications and assumptions during model building, there will always be inaccuracies (Bertrand and Fransoo, 2016). Therefore, an effort has also been put into discussing the results beyond the numbers. Another part of the results, as presented in Chapter 6, is to show how an economic model can be applied when initiating remanufacturing. In the proposed five-step approach, validation of the economic assessment is continuously conducted in Step 3 as more information is gathered; see Chapter 6. This has been conducted in a similar manner as described above, where every part of the model is validated. As the last step of the proposed five-step approach, the validation and refinement of the conducted economic assessment are proposed.

Reliability of data. The reliability of the collected data has been covered briefly above. However, it is worth repeating. Triangulation has been used to ensure both theory and empirical data are interpreted accurately. This approach is appropriate in case study research (Yin, 2018). In terms of applied theory, reliance is put on founding the theoretical bases on multiple sources. In contrast, in terms of empirical data, the same type of questions has been directed towards several individuals from different backgrounds and work positions during interviews as well as continuously communicating the progress and data used between the researchers and the case company representatives.

With regard to validating the results for the first research question on remanufacturing prerequisites, each factor is valid in the sense that it relies on theory as well as the case study. The factors were also influenced by manufacturing theory, from which links were drawn to a remanufacturing setting. The found prerequisites have therefore been validated for the conducted case by the validation techniques presented here. However, in terms of generalisability, validating the prerequisites for other types of companies and products is left for further research as per the delimitations of this thesis.

There is also a question of whether an external researcher can access the dataset to confirm the results. Such procedures are not possible here due to sensitive data that limit transparency. The data set used in this research study can therefore not be disclosed to other researchers. Instead, the research has been guided by openness by being transparent in how the research has been conducted and how the results should be interpreted. By following the method listed here, it should be possible to replicate the findings and draw similar conclusions. Moreover, when viewing Papers II and III, the scientific contributions are not the numeric values presented to the case company but the approach taken, recommendations given, and conclusions drawn to provide guidance when initiating remanufacturing. These contributions can be validated using other data sets. For Paper I, the motivation is analogous but without numerical results.

3 THEORETICAL FOUNDATION

The third chapter provides a common frame of reference between the reader and the research study. The theoretical foundation starts broadly with remanufacturing in the context of a circular economy. As the chapter progresses, the content narrows down from a product life cycle perspective to the remanufacturing system and its internal and external processes. Subsequently, what remanufacturing is and how it behaves in a larger context are covered.

3.1 REMANUFACTURING

Remanufacturing is an industrial process in which a core – a used, discarded, or broken product – is transformed into a product whose specification and condition are like new (Lund, 1984). Since these products should be just like their new counterparts, some researchers argue for a definition where all remanufactured products also must come with a warranty (Ijomah, 2002). In a remanufacturing setting, the perception of the product is important to provide a sellable offer. Even though remanufacturing is believed to have been performed for centuries on locomotives (Guide and Van Wassenhove, 2009) and gained traction from 1920 to 1950 due to resource scarcity in the automotive and military industries (cf. Guide et al., 2003; Lund, 1984; Sundin, 2004), the process is relatively unknown to the public (Cao et al., 2020; Parker et al., 2015). Therefore, to ensure the customer understands the product's value – other than providing evidence that the remanufacturer delivers as promised – providing a product warranty similar to that of new products is important (Ijomah, 2002).

In fast-moving markets where technical products rapidly suffer from substitution and obsolesce due to the release of more advanced new products (Porter, 1998), providing remanufactured products can be difficult since a perceived outdated product could be unattractive to the customer (Östlin et al., 2009; Seitz and Peattie, 2004). This depends highly on market characteristics and the acceptance of products that do not deliver the latest features and functionality. For example, in markets with high green-conscious customers or high price sensitivity, remanufactured products can still score high on demand (Abbey et al., 2015b). However, in other types of markets, remanufacturing could be unattractive to the level that it is not worth performing (Atasu et al., 2010). Therefore, upgrading could be considered an internal remanufacturing process, and the remanufacturing process could be defined thereafter (Ijomah, 2002; Ijomah and Danis, 2012).

A generic remanufacturing process consists of seven internal processes in an arbitrary order, namely *cleaning*, *inspection*, *disassembly*, *storage*, *reprocessing*, *reassembly*, and *testing* (Sundin, 2004). Depending on the product type, the internal processes of a remanufacturing process vary since all products do not need to undergo the same processes to restore them to new-like condition. For example, the process steps utilised during the remanufacturing of toner cartridges are not the same as those used in the remanufacturing of forklift trucks due to different designs and needs (Sundin et al., 2016). A remanufacturing process of toner cartridges could consist of sorting based on quality, disassembling, cleaning, refilling, reassembling, and testing, while for forklift trucks, there is also a step for reprocessing of broken parts, requiring a wide range of operations depending on both part type and condition.

3.2 REMANUFACTURING IN A CIRCULAR CONTEXT

During the 1970s, the CE started to become a widely accepted concept to describe a closed-loop resource system (EMF, 2013). The CE has several definitions. For example, the Ellen MacArthur Foundation (EMF, 2015) described the CE as "[…] restorative and regenerative by design and aims to keep products, components and materials at their highest utility and value at all times, distinguishing between technical and biological cycles". This definition has two main distinctions, namely, biological and technical flows, as seen in Figure 5. As an industrial process, remanufacturing is directly part of the technical flows. However, the distinction between the technical and biological flows is not as clear in reality, meaning that remanufacturing operations can influence on the CE from a wide perspective.

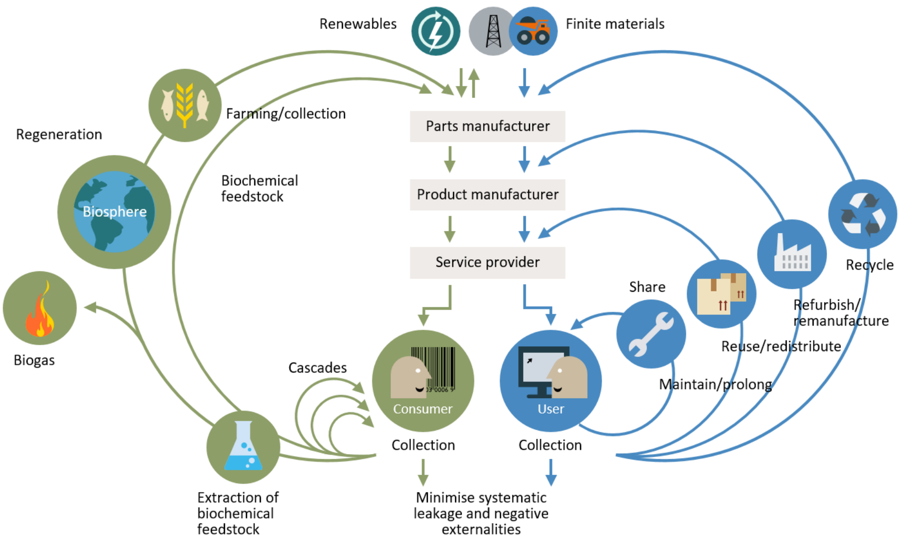

Figure 5. The Ellen MacArthur Foundation butterfly diagram of the circular economy (EMF, 2019).

Another widely cited definition of the CE posited by Geissdoerfer et al. (2017) is "a regenerative system in which resource input and waste, emission, and energy leakage are minimised by slowing, closing, and narrowing material and energy loops. This can be achieved through long-lasting design, maintenance, repair, reuse, remanufacturing, refurbishing, and recycling". No matter which definition of CE is used, remanufacturing tends to be considered among many other value-retention processes (VRPs) (Nasr and Russel, 2018) or one of many Rs that transition resource flows from linear to more circular ones (Kirchherr et al., 2017; Potting et al., 2017). However, the R corresponding to remanufacturing tends to have low priority in studies conceptualising the Rs. That position of remanufacturing has been criticised since it views remanufacturing as inferior to other processes that retain values within a CE (Kurilova-Palisaitiene and Sundin, 2021).

By being part of a CE, remanufacturing contributes to the Brundtland Commission's definition of sustainable development[1], as the process contributes to positive effects on the economic (Linton, 2008; Parker et al., 2015; Sundin et al., 2016), environmental (Kerr and Ryan, 2001; Lindahl et al., 2006; Sundin and Lee, 2011), and social performance (Benoy et al., 2014). The triple bottom line – differentiated into the dimensions of economic, environmental, and social (Elkington, 1998) – is therefore contributed towards when successfully performing remanufacturing. Acting upon

[1] "Sustainable development is development that meets the needs of the present without compromising the ability of future generations to meet their own needs" (WCED, 1987, p. 54).

such principles enables economic growth concurrently with reduced environmental impact, enabling the decoupling of the two dimensions (Gilli et al., 2017). Companies could, therefore, continue to output products and be profitable while reducing their environmental impact (Garetti and Taisch, 2012).

From the CE perspective, Sundin (2020) metaphorically depicted remanufacturing as the heart and lungs, meaning that remanufacturing acts as an imperative enabler and facilitator for a CE. However, to achieve these synergy effects, remanufacturing must also be managed appropriately. Drivers for remanufacturers are many, for example, cost reductions, protection of aftermarkets, and reduced environmental impact (Östlin et al., 2008a). But to grasp these, a level of managerial decision-making is needed for companies to position remanufacturing appropriately (Rizova et al., 2020). For this, a standpoint in the product life cycle can be taken where remanufacturing has the role to manage and prolong the life span of products reaching their end-of-life (Cao and Folan, 2012). In the next subchapter, this perspective is further emphasised.

3.3 MANAGING REMANUFACTURING

In the process of running a manufacturing company, it is essential to create a product that is competitive in the market and can provide positive cash flows (Porter, 1998). However, due to changing markets, the attractiveness of products varies over time in a bell-like pattern known as the economic product life cycle. Here, technological innovation is key to staying competitive (Abernathy and Clark, 1985). While remanufactured products are not immune to obsolescence due to declined attractiveness (Seitz and Peattie, 2004), remanufacturing could provide a differentiation strategy that increases the attractiveness of products through other means, such as cost reductions and targeting additional customer segments (Atasu et al., 2008b). Thus, the shape of the life cycle curve is influenced by remanufacturing.

For OEMs to encapsulate remanufacturing, a shift in their way of operating from new manufacturing-centric to also considering the management of end-of-use products must be realised. Kurilova-Palisaitiene (2021) proposed a four-step tool to undertake such a shift: (1) define product suitability, (2) measure readiness level, (3) estimate benefits, and (4) develop an implementation plan. Similarly, Subramoniam et al. (2010) developed a remanufacturing decision-making framework. Since it is difficult to predict and manage remanufacturing (Daniel et al., 2000), tools like these are necessary to motivate a worthwhile transformation (Bocken et al., 2016; van Loon and Van Wassenhove, 2020).

Moreover, when viewing remanufacturing based on a technical product life cycle perspective where products undergo several alternative VRPs (Nasr and Russel, 2018), it is clear that there is a multitude of elements to consider when initiating remanufacturing; see Figure 6. Deciding on how remanufacturing is performed in relation to other VRPs is influenced by several factors, for example, the order of the waste hierarchy (Gharfalkar et al., 2015), the Rs (Kirchherr et al., 2017; Potting et al., 2017), or through decision-making support tools (Rizova et al., 2020; Subramoniam et al., 2013). Consequently, to determine whether remanufacturing is worth initiating, its competitiveness in relation to other alternatives and the perception of remanufactured products on the market must be investigated (Yang et al., 2016).

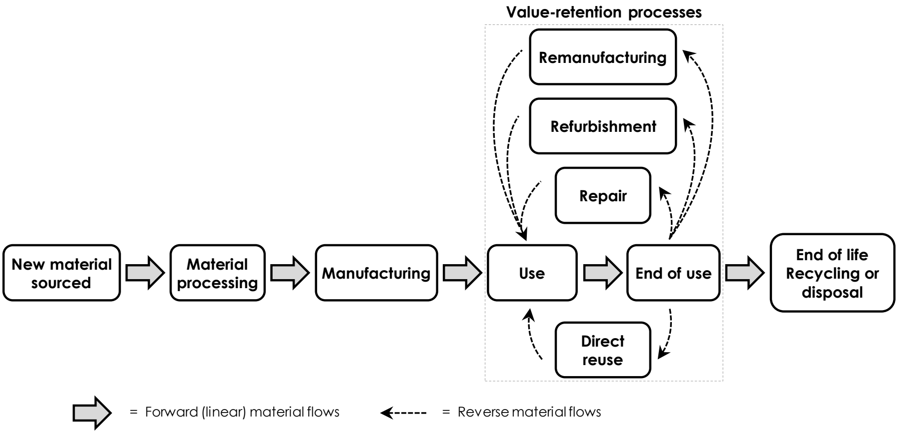

Figure 6. A product life cycle of a product that undergoes several value-retention processes. Based on Nasr and Russel (2018).

Measuring the competitiveness of remanufacturing is performed by applying assessment methods. This area has been researched from various perspectives, for example, production planning and control (Junior and Filho, 2012), scheduling (Morgan and Gagnon, 2013), and disassembly (Priyono et al., 2016) to improve the performance of remanufacturing. Additional studies focus on techniques to assess the feasibility of remanufacturing (Goodall et al., 2014). Related are the economic assessment models developed by van Loon et al. (2020) using NPV, Lahrour et al. (2019) utilising a direct comparison, and Alamerew and Brissaud (2020) with system dynamics. These can provide decision-making insights into whether remanufacturing initiations are worthwhile.

Managing all steps of the technical product life cycle is central in a CLSC system (Guide and Van Wassenhove, 2009). Regarding remanufacturing, such a system focuses on securing the efficient return of cores, which enables the possibility for remanufacturing, but also other supply chain activities from material extraction to processing and end-of-life (Guide and Van Wassenhove, 2009). However, these activities are also influenced based on product characteristics, company visions, and business models (Govindan et al., 2015). By then adding further factors, the CLSC perspective expands towards areas of economics, sales, cannibalisation, design, quality concerns, and information exchange (Shekarian, 2020). From this, parallels can be drawn to a remanufacturing system that handles all activities in the periphery of a remanufacturing process (Östlin, 2008).

3.4 Remanufacturing system

The remanufacturing system has been encapsulated by Östlin (2008) as "the system for collecting used/discarded products, remanufacturing of the product, and the delivery of the remanufactured products to the customer". The concept is depicted in Figure 7. As seen, there are two main parts of the system. The internal processes are the central organ of a remanufacturing system since they actively transfer the inputs (the cores) to outputs (remanufactured products), similarly to how a traditional production system transforms raw materials into new products; see Subchapter 3.1. Meanwhile, the external processes act as the deliverer of resources and extractor of finished goods. Collaboratively, core acquisition, internal processes, and sales processes contribute to capturing and retaining the value of products that otherwise would have been discarded, thus closing the resource loop.

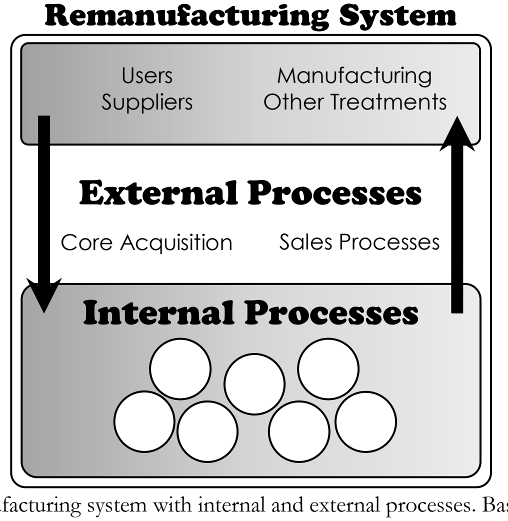

Figure 7. The remanufacturing system with internal and external processes. Based on Östlin (2008).

Another iteration of the remanufacturing system has been developed by Barquet et al. (2013). They view the remanufacturing system with a basis in general system theory and introduced six sub-elements – *design for remanufacturing*, *reverse supply chain*, *information flow in the remanufacturing system*, *employees' knowledge and skills in remanufacturing*,

remanufacturing operation, and *commercialisation of the remanufactured product* – to present an integrated view of the system. This view is much broader than Östlin's (2008) system and provides a more detailed illustration of factors that make all remanufacturing processes work together seamlessly. In the following subchapters, the theoretical foundation takes a stand in the former remanufacturing system and describes the two external processes, namely core acquisition and sales. Further coverage of the remanufacturing system is presented in Chapter 4.

3.4.1 CORE ACQUISITION PROCESSES

A remanufacturing system is highly dependent on the inflow of cores since these make up the primary resources needed to perform remanufacturing (Lund, 1984). As such, without cores, there is no process feasibility. Moreover, as cores are used products, they need to be returned from the current user. Core acquisition can be challenging for companies as it is difficult to forecast how many cores are available for collection and to influence how frequently they arrive (Guide, 2000). This highlights core acquisition as a primary characteristic of remanufacturing (Sakao and Sundin, 2019; Wei et al., 2015c). Compared to manufacturing, where the input resources are primarily raw materials from known and consistent sources or parts directly from suppliers, acquiring cores intended for remanufacturing is on another level in terms of complexity and uncertainty (Daniel et al., 2000). As such, the user or product owner needs to be contacted, and the buyback process arranged. There are seven CLSC relationships that can be applied to ease the acquisition process (Östlin et al., 2008b); see Table 5.

Table 5. The seven closed-loop supply chain relationships used to arrange core acquisition for remanufacturing. Based on Östlin et al. (2008b).

Relationship	**Principle**
Buy-back	Cores are bought from the product owner.
Credit-based	Cores are exchanged for discount credits valid when buying remanufactured products.
Direct-order	Cores are remanufactured on behalf of the product owner.
Deposit-based	Cores enable the purchase of a similar remanufactured product.
Ownership-based	Cores are owned by the provider throughout the use period.
Service-contract	Cores are remanufactured as part of a contract.
Voluntary-based	Cores are returned voluntarily.

Generally, it is not possible to state that a certain CLSC relationship is better than another. The reason is that, given a certain product, market circumstance, or business model, the advantages and disadvantages of each relationship vary (Östlin et al., 2008b). However, it is commonly easier for a remanufacturer to acquire cores in a controlled manner if the ownership is kept by the remanufacturer throughout the use period of the product (Guidat et al., 2014; Sundin and Bras, 2005). Then, when it is time for remanufacturing, the remanufacturer can demand a product return without having to provide a monetary incentive (Östlin et al., 2008b). Commonly, such arrangements are known as selling service offerings – functionalities and features instead of products – through a product-service system (PSS) (Tukker and Tischner, 2006). These offerings, such as leasing, can provide economic and environmental benefits to service providers and users (Lindahl et al., 2014).

When the acquisition of cores cannot be controlled, the process is considered uncertain and adopts a stochastic behaviour (Goltsos et al., 2019). This uncertainty can be lowered by applying core acquisition management. A review study in this area conducted by Wei et al. (2015c) listed five factors to consider that influence the volume, timing, and quality variation of core acquisition; see Table 6. The presented CLSC relationships are part of the return strategies (Östlin et al., 2008b).

Table 6. Five core acquisition management principles used to reduce uncertainties in the acquisition process. Based on Wei et al. (2015c).

Core acquisition management	**Principle**
Acquisition control	Incentivises the return of cores, thus affecting the returned quantity.
Quality classification	Categorisation to determine whether to accept a core, how it can be restored, and to which price.
Return forecast	Procedures to assess the expected availability of cores, arrival rate, and volume.
Return strategies	Arrangements of how cores are acquired. E.g., see Table 5.
Reverse channel design	Logistics of how cores arrive to remanufacturing facilities.

Acquisition control is built upon the principle of adjusting the incentive that motivates the product owner to return the product to the remanufacturer to achieve a consistent and predictable flow of cores (Wei et al., 2015c). Given an inflow higher than the throughput rate of the remanufacturing process, the provided incentive can be decreased. As a result, the acquisition cost is reduced through either lower buyback cost (for certain return strategies) or lower inventory levels (Wei et al., 2015c). Analogously, a weak inflow requires an opposite action. However, which measures can be taken depend on a chosen return strategy (Östlin et al., 2008b). For example, in a PSS, the management of cores can be built into the contract stating how and when cores should be returned, thus not requiring an economic incentive to motivate the return activity (Yang and Evans, 2019). Instead, thorough planning is needed to ensure that the expected returns align with the capability of the remanufacturing process. Such planning is part of the return forecast (Wei et al., 2015c).

Forecasting and controlling the arrival of cores is not the only present uncertainty within core acquisition management (Wei et al., 2015a). Cores of varied quality require a wide and differentiated range of process steps (Kurilova-Palisaitiene et al., 2018). Therefore, forecasting the quality of the cores is important. However, it is also a challenging feat to master (Kurilova-Palisaitiene et al., 2018) due to both use patterns (Kuo, 2011) and variations in the planned durability leading to various levels of failure (Östlin et al., 2009). In some cases, the quality level of a core can be insufficient due to, for example, technical obsolescence or economic reasons, meaning that the core is not usable for remanufacturing (Zhou and Gupta, 2019).

Applying an approach to classify cores early in the process, and depending on the return strategy, it can be prevented that the core is acquired in the first place or that it is filtered out from the system as soon as possible (Errington and Childe, 2013; Ridley and Ijomah, 2015). The classification can also provide economic benefits since the internal remanufacturing process can be adjusted based on quality classes, leading to a streamlined and efficient process (Wei et al., 2015b). However, a low and fixed number of quality classes should be set as too many could lead to an unproportionable increase in administrative costs (Wei et al., 2015b).

3.4.2 SALES PROCESSES

Providing a sellable product is the fundamental step of any company that designs, develops, and creates a product (Porter, 1998). Even for new products, if there is no market demand, the business cannot continue. For remanufactured products, there is prior knowledge that the original product has been demanded by the market. However, since markets are constantly evolving due to, for example, technical advances (Östlin et al., 2009) and consumer preferences, it is not proof that a remanufactured product will be sellable as well (Abbey et al., 2015a). For example, remanufactured products could be technically obsolete (Kwak and Kim, 2015; Östlin et al., 2009), uncompetitive in terms of pricing (Sundin et al., 2016), or unattractive from a product characteristic point of view (Abbey et al., 2015a; Kabel et al., 2021).

Customer willingness to pay is a measure of how attractive a product is in relation to monetary value. A simple view of the concept is the traditional supply and demand curve (Samuelson and Marks, 2015); see Figure 8. The relation between the curves is dependent on the perceived value of the remanufactured product and is an integral parameter to consider when aiming for profitable remanufacturing (Abbey et al., 2015b). With high perception, the customer willingness to pay for remanufactured products is high (Abbey et al., 2015a). Analogically, with low perception, few will buy.

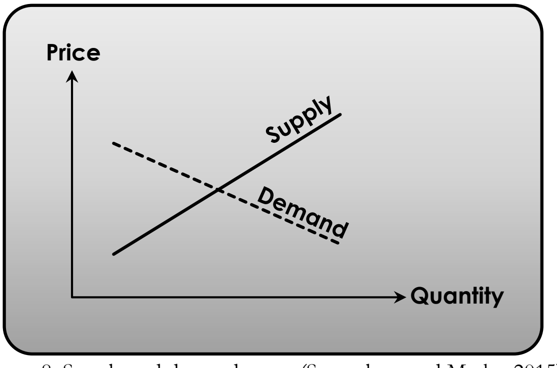

Figure 8. Supply and demand curve (Samuelson and Marks, 2015).

From a business point of view, remanufacturing must be economically attractive; otherwise, companies will not perform the process (Östlin et al., 2008a). Finding the balance between price and cost, therefore, is imperative given that there is a demand for the product. It is seldom the case that remanufactured products are valued higher than new counterparts (Giutini and Gaudette, 2003; Subramanian and Subramanyam, 2012; Sundin et al., 2016). Therefore, from the perspective of the OEMs, assuming that remanufactured products perfectly substitute new products one-for-one, the remanufacturing process must be more resource efficient than manufacturing to be economically beneficial (Atasu et al., 2008b; Parker et al., 2015). Otherwise, remanufacturing is not as profitable as manufacturing. This type of substitution is known as cannibalisation of sales (Atasu et al., 2010; Guide and Li, 2010).

Without perfect substitution, there are potential cases where remanufacturing could result in an increased total number of sold new and remanufactured products combined, as described by Ovchinnikov et al. (2014) and Guide and Li (2010), thus leading to higher profitability even if the remanufacturing process is not able to lower the process costs to sufficient levels. For example, remanufactured products could be sold to new markets with no competition with new counterparts or reach new customer segments in an existing market (Abbey et al., 2015a; Atasu et al., 2008a), thus nullifying the cannibalisation threat (Okorie et al., 2021). During prosperous remanufacturing circumstances but with a low supply of remanufactured products, *seeding* or *downward substitution* – that is, selling new products as remanufactured – can be applied to penetrate new markets and ensure sufficient supply as well as promote the quality of remanufactured products (cf. Abbey et al., 2019; Ahiska and Kurtul, 2014).

During less prosperous conditions, incentives such as subsidies could promote the attractiveness, sales volume, and profitability of remanufacturing (Mitra and Webster, 2008; Zhou and Yuen, 2020). The reputation of the seller could also influence it (Kabel et al., 2021). Many customers tend to prefer remanufactured products from authorised sources, such as remanufactured products certified or produced by OEMs, over other alternatives (Subramanian and Subramanyam, 2012). The type of business model also impacts on how well remanufactured products can be sold. As a circular VRP (Nasr and Russel, 2018), remanufacturing can easily be integrated into circular business models (Bocken et al., 2016; Parker et al., 2015). There is a selection of circular business models that can be applied in the context of a CE to either slow or close resource loops and influence how remanufactured products can be offered to customers (Bocken et al., 2016), as shown in Table 7. For example, in the *classic long-life* model, remanufactured products are sold as a traditional one-of-sale, while in *access and performance*, a PSS is applied. Furthermore, a selected business model influences the selection of distribution and sales channels for remanufactured products (Geissdoerfer et al., 2018).

Table 7. Six circular business model types. Based on Bocken et al. (2016).

Business model	**Principle**
Access and performance	Slowing resource loops by selling the functionality instead of a product.
Classic long life	Slowing resource loops by selling a highly durable and repairable product.
Encourage sufficiency	Slowing resource loops by selling durable products whose life is easily prolonged using small inputs.
Extending product value	Slowing resource loops by retaining the value of end-of-use products.
Extending resource value	Closing resource loops by collecting otherwise wasted resources and materials and retaining their value.
Industrial symbiosis	Closing resource loops by turning industrial waste products into usable resources.

4 PREREQUISITES FOR REMANUFACTURING

The fourth chapter of this licentiate thesis introduces four essential and four supporting factors to consider when initiating remanufacturing. These are conceptualised as 'the remanufacturing rocket'. The position of every factor in the context of remanufacturing is primarily exemplified based on theoretical contributions and secondly founded in empirical data from the case study.

In this chapter, the first research question is targeted: *RQ1. What prerequisites are needed when initiating OEM remanufacturing?* When initiating remanufacturing, there are many aspects to consider (Kurilova-Palisaitiene, 2021; Subramoniam et al., 2010) since remanufacturing reshapes the traditional value streams of OEMs to include reverse logistics and reprocessing of cores (Guide and Van Wassenhove, 2009). An initiation also adds another level of uncertainties in areas such as core quality (Kurilova-Palisaitiene et al., 2018) and arrival rate (Guide, 2000; Wei et al., 2015c).

A remanufacturing process tends to be complex due to a multitude of uncertainties, thus requiring actions to overcome these (Sakao and Sundin, 2019). During the initiation phase, therefore, it is important to understand the prerequisites of remanufacturing, that is, what considerations are needed to successfully initiate remanufacturing practices. As described in Paper I, eight such factors were found: *remanufacturing process and technology*; *core acquisition and reverse logistics; remanufacturing facilities; labour skill and availability; organisation, planning, and control; remanufacturing market knowledge; remanufacturing process improvements;* and *design for remanufacturing and information* *feedback*. These factors were founded in the manufacturing categories, as described by Lekurwale et al. (2015) and Miltenburg (2008, 2005): human resources, process technologies, facilities, sourcing, organisational structure and control, and production planning and control. Thereafter, based on remanufacturing literature and the conducted case study, the factors were translated and extended into remanufacturing terms.

The former four factors are classed as *essential* when initiating remanufacturing, while the latter four are classed as *supporting*. These two classes are further covered in Subchapters 4.1 and 4.2, respectively. Together, these factors are depicted as the parts of a rocket – *the remanufacturing rocket* – as illustrated in Figure 9. The rocket metaphorically represents the journey an OEM takes when transitioning from solely manufacturing operations to also being a remanufacturer. Launching a rocket from the earth is a complex process, but so is also initiating remanufacturing practises. To make the transition, certain know-how about remanufacturing is needed, know-how which the eight identified factors conceptualise.

The essential factors can be viewed as the core structure of the rocket that enables travel to a designated destination in space where remanufacturing is successfully achieved. However, without an attached steering mechanism, it is not certain that the fullest potential of remanufacturing can be reached. The four supporting factors make it possible to adjust the path of the rocket, hence making it easier to reach the target and all the benefits remanufacturing can bring.

In subchapters 4.1 and 4.2, motivations for why the prerequisite factors are classed as essential and supporting, respectively, are provided; see Tables 8 and 9 for a summary. These motivations are founded in the case study. In the subsequent chapters, each of the prerequisites is defined by exemplifying their content with a theoretical basis. For the essential factors, the theoretical basis is followed by a short insight from the case study.

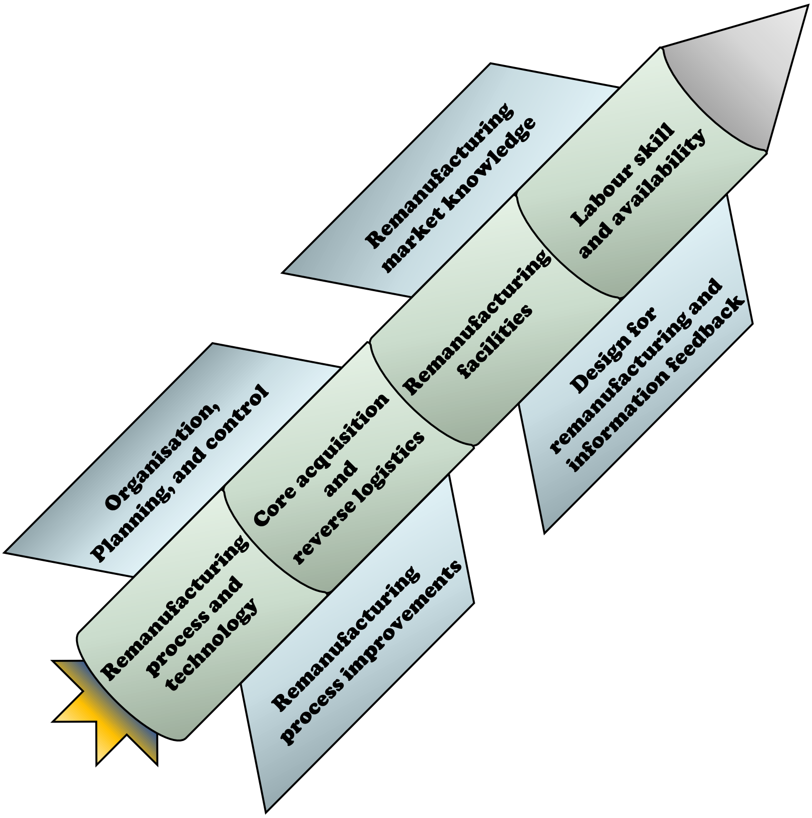

Figure 9. An illustration of the remanufacturing rocket, consisting of essential (the body) and supporting (the wings) factors, that together enable successful remanufacturing. Based on Vogt Duberg et al. (2020) in Paper I.

4.1 ESSENTIAL FACTORS FOR REMANUFACTURING

Here, certain considerations of the case company's readiness for remanufacturing based on its existing supply chain are presented. It indicates what are considered to be essential prerequisite factors for remanufacturing. The case study showed that remanufacturing could be realised at several different locations within the case company's existing supply chain. It could also have been positioned elsewhere, but utilising an already developed logistics network was considered valuable as new investments and developments were kept low. The supply chain and the logistics network enable access to spare parts in the remanufacturing process as well as channels to retrieve cores from the product owners. At the time of the study, most cores had been sold through a traditional one-of-sale business model, meaning that the case company had lost ownership of the products. Most of the products have also been sold by the network of retailers, a network that maintains the communication channels with the product owners.

At the case company, the retailers also have the highest knowledge of how the products perform during usage and how to repair them. Therefore, the retailers are not only suitable actors to acquire cores but also to conduct remanufacturing in a job shop environment. Hence, decentralised remanufacturing at selected retailers was found to be feasible. However, the case company also possesses the required knowledge for remanufacturing, meaning that centralised remanufacturing within the existing supply chain was also a possibility. It could potentially be performed at a higher efficiency thanks to greater availability of equipment, a proper manufacturing environment, and economies of scale.

This view of the potential remanufacturing process at the case company exemplifies the fundamental requirements when initiating remanufacturing. Firstly, the internal processes must be realised, and the right equipment needs to be accessible; otherwise, it is not possible to make any reprocessing steps to restore a core to a new-like condition. Secondly, the cores must be brought to the selected location and processed. Thirdly, a location for the process is necessary, and where it is positioned influences what needs to be developed from scratch. Finally, the workers that performed the internal and external processes are needed to actively fuel the transformation.

A further theoretical exemplification of the four essential factors is presented in the subsequent chapters. The basis of the factors is that if one is completely neglected, it is impossible to perform remanufacturing from start to finish. The main motivations are listed in Table 8.

Table 8. The motivation basis for why the prerequisite factors are labelled essential for remanufacturing. Based on Vogt Duberg et al. (2020) in Paper I.

Prerequisite factor	Reason for essential
	There must be…
4.1.1 Remanufacturing process and technology	… a sequence of process steps and technologies to remanufacture cores.
4.1.2 Core acquisition and reverse logistics	… cores available to remanufacture and ways to transport them to remanufacturing facilities.
4.1.2 Remanufacturing facilities	… a remanufacturing facility where remanufacturing is performed
4.1.4 Labour skill and availability	… workers available with the right skillset to perform remanufacturing.

4.1.1 REMANUFACTURING PROCESS AND TECHNOLOGY

The remanufacturing process is integral as it facilitates the operations that restore cores to a new-like condition. Without it, there is no remanufacturing possible. However, remanufacturing tends to be a complex and uncertain process (Goodall et al., 2014; Lundmark et al., 2009; Sakao and Sundin, 2019), meaning that the process and the technology used need to undergo thorough planning to be effective and efficient. The manufacturing attribute *flexibility* enables an agile industrial process capable of adapting to new requirements in a timely manner (Miltenburg, 2005), thus creating the basis for a remanufacturing process capable of handling cores requiring varied reprocessing steps and the irregular arrival of cores.

One of the steps when creating a remanufacturing process is determining which type of industrial process to utilise. Typically, highly automated systems tend not to be highly flexible, for example, continuous or equipment-paced line flows (cf. Dallery and Gershwin, 1992; Lee, 1992; Miltenburg, 2005). However, it is a matter of case-to-case as remanufacturing challenges are commonly company-specific (Lundmark et al., 2009). For example, on the one hand, the case study by Shahbazi et al. (2021) showed automation as an enabler for flexible remanufacturing processes, given that products were designed for remanufacturing. On the other hand, Sakao and Sundin (2019) and Sundin et al. (2020) exemplified successful cases of automated remanufacturing but also highlighted the inherent uncertainty of remanufacturing as a barrier to automation.

Less complex and more manual industrial processes facilitated by production systems like job shop and batch flow have high capabilities in flexibility, but in comparison, lack in delivering high volumes (Miltenburg, 2005). In decentralised remanufacturing settings, these industrial processes could be suitable as multiple remanufacturing facilities could achieve a high total remanufacturing volume.

For the conducted case study in this thesis, both centralised and decentralised remanufacturing have been assessed; see Chapter 5 – Economic assessment of remanufacturing – for further elaboration. The chosen type for the decentralised system was job shop as it induces low requirements on setting up the process. It is also easy to operate as long as the operator is experienced. For the centralised process, a semi-automated industrial process with high manual input was identified as suitable as it resembled the product system already in place at the case company. The more advanced proposed production system also satisfied higher demands on throughput rate.

4.1.2 CORE ACQUISITION AND REVERSE LOGISTICS

The remanufacturing process requires cores as fuel (Lund, 1984). Without cores, the process cannot continue operating since there are no resources to create a remanufactured product. Therefore, access to cores is a fundamental requirement (Sakao and Sundin, 2019). It is also considered a common challenge to overcome among operating remanufacturers (Sundin et al., 2016). The remanufacturers have several alternatives to how cores are acquired, for example, by purchasing cores from core brokers (Lind et al., 2014; Lund, 1984) or applying any of the seven closed-loop supply chain relationships identified by Östlin et al. (2008b); see Table 5 in Subchapter 3.4.1. As such, the owners of cores could receive incentives to hand over cores for remanufacturing (Östlin et al., 2008b).

However, cores must not only be identified but also transported to a remanufacturing facility. The transport is realised through a reverse logistics channel (Guide and Van Wassenhove, 2009). Here, how the channel is carried out is influenced by product characteristics, company goals, and the applied business model (Govindan et al., 2015). For example, a bulky core might require a more thoroughly planned and advanced channel than a smaller one. In comparison, the cores of the case company are rather manageable. Therefore, the owners of the cores could hand them in to the nearest retailer, and the retailer then forwards them to the remanufacturing facility.

Sundin and Dunbäck (2013) identified handling, transportation, and storing of cores as critical concerns at small and medium-sized enterprises. Core acquisition management is the approach to managing these and other concerns (Daniel et al., 2000). The approach can influence how cores arrive at the remanufacturing facility as well as how the quality of cores is managed (Wei et al., 2015c). This ensures that the incoming cores meet the quality requirements of feasible remanufacturing (Ferrer, 2001; Kurilova-Palisaitiene et al., 2018).

4.1.3 REMANUFACTURING FACILITIES

A remanufacturing facility is the remanufacturing equivalent of a manufacturing plant. The facility contains the remanufacturing process and acts as a hub and link to a logistics network (Ferrer and Whybark, 2000). The location of the facility is important from several perspectives. For example, how the facility is integrated into the supply chain network impacts the overall economic and environmental performance (Cheng et al., 2015; Dowlatshahi, 2005) and, therefore, how well remanufacturing is performed. Resources and finished goods should be transported to and from the location efficiently, and the operation of the remanufacturing process should be suitable for the task at hand. As such, the location sets limits to the access and costs of cores as well as how efficiently remanufactured products can be delivered to the market (cf. Jakubicek and Woudsma, 2011; Karakaya and Canel, 1998; Min and Melachrinoudis, 1999).

The choice of location is also of importance in terms of access to the right competence. Remanufacturing tends to be a labour-intensive process (Guide and Van Wassenhove, 2001; Sakao and Sundin, 2019), making the proximity and access to the right expertise critical considerations (Jakubicek and Woudsma, 2011; Lu et al., 2014). Remanufacturing and manufacturing operations could also be performed under the same roof, creating a hybrid system (Wei et al., 2015c). In that manner, it is also possible to gain synergy effects by utilising the same networks, resources, and competences between the two industrial processes. However, realising such a system is challenging (Kurilova-Palisaitiene et al., 2018).

In the case study, these factors were considered when identifying a suitable remanufacturing location for the case company. Utilising the existing logistics network of the case company was considered beneficial as it would enable transport possibilities for cores and remanufactured products. Within the logistics network, there were several manufacturing plants and repair workshops. These sites facilitate easily identifiable individuals with product-specific knowledge. Therefore, in terms of both logistics and skill requirements, this is an example of how an overview of potential locations could be derived.

4.1.4 LABOUR SKILL AND AVAILABILITY

As briefly covered in Subchapter 4.1.3, finding and utilising the right employees with the right expertise is valuable for achieving effective and efficient remanufacturing operations. Due to high variation in the procedures required to restore the incoming cores to new-like condition, the remanufacturing process needs to have high capabilities to adjust to the requirements of each core (Sakao and Sundin, 2019) and maintain the flexibility for long periods (Georgiadis and Athanasiou, 2013).

The remanufacturing process is not only labour-intensive (Guide and Van Wassenhove, 2001; Sakao and Sundin, 2019); it also demands highly skilled workers to perform inspection, disassembly, and reassembly during the remanufacturing process (Seitz and Peattie, 2004). Furthermore, the workers must be able to consistently perform all the internal processes of the remanufacturing process as well as perform all other process steps of remanufacturing (Sundin and Bras, 2005). The skillset of the remanufacturing workers directly translates to productivity levels and profitability potential of the remanufacturing process (Giri and Glock, 2017).

Depending on the circumstances, personnel with experience in repairing or manufacturing could be suitable when initiating new remanufacturing processes. For the case company, the existing repair workshops possess experience and knowledge on how to disassemble and perform restorative operations on the product. This knowledge could be used as a basis when building up the remanufacturing expertise when the initial skillset is lacking.

4.2 SUPPORTING FACTORS FOR REMANUFACTURING

During the case study, the four supporting factors were not highly considered. As per the listed motivations in Table 9, the factors were not critical when exploring the remanufacturing prospects. For example, remanufacturing process improvement is integral to achieving an efficient and effective process that contributes positively to the balance sheet. However, when exploring the feasibility of the main principles of remanufacturing, efficiency and effectiveness are subject to later considerations since realising the fundamentals, like access to cores and necessary workers, is more significant. Therefore, these factors are classed as supporting prerequisite factors for remanufacturing. A further theoretical exemplification is presented in the subsequent chapters.

Table 9. The motivation basis of why the prerequisite factors are labelled as supporting for remanufacturing. Based on Vogt Duberg et al. (2020) in Paper I.

Prerequisite factor	Reason for supporting
4.2.1 Remanufacturing process improvement	To make the remanufacturing process more efficient.
4.2.4 Design for remanufacturing and information feedback	To enable synergy effects between product designers and best practices to make remanufacturing efficient and profitable.
4.2.2 Remanufacturing market knowledge	To understand market perceptions and demands for remanufactured products, which helps in adapting remanufacturing offers for the market.
4.2.1 Organisation, planning, and control	To reduce uncertain process behaviour, as well as improve effectiveness, yield, and quality of remanufacturing.

4.2.1 ORGANISATION, PLANNING, AND CONTROL

This factor is defined from the point of view of initiating remanufacturing. In terms of manufacturing, when starting up an industrial process, a product introduction process (Johansen, 2005) or a ramp-up phase (Clark and Fujimoto, 1991) is undertaken. Here, the product at hand is integrated with a production system and trial runs are performed to make sure everything works according to plan. This procedure founds a system capable of creating new products (Bellgran and Säfsten, 2009; Juerging and Milling, 2005). However, the realisation of the procedure varies depending on the given circumstances. For example, given a case of low volumes and uncertain demand, Javadi et al. (2016) indicated that a time-consuming product introduction process might not be worthwhile. Instead, the focus should be put on drawing parallels from previous experiences and other similar industrial processes.

Since remanufacturing processes tend to output smaller batches in comparison to manufacturing (Seitz and Peattie, 2004) and also suffer from high variability and uncertainty throughout the process (Kamper et al., 2019; Kurilova-Palisaitiene et al., 2018; Lundmark et al., 2009), applying analogies with Javadi et al.'s (2016) findings, a remanufactured product introduction process is of low importance despite its potential benefits. Furthermore, the higher the remanufacturing throughput rate, the more reliance there is on the organisation, planning, and control structure to make the process realisable. The argumentation here is that these three aspects enable comprehension of how a core is transformed into a remanufactured product. For example, a thoroughly planned remanufacturing process keeps wastes at a low level and lead times short (Kurilova-Palisaitiene et al., 2018). A clear understanding of the process makes the procedure replicable; however, it is not fundamental for outputting remanufactured products. For example, remanufacturing a single car in an industrial environment without a present organisation, planning procedure, or control organ is possible but likely unproportionally time consuming.

To coordinate the internal and external remanufacturing processes, the factor can provide positive synergy effects between various areas, for example, enabling access to the right equipment at the right time, distributing cores within the organisation, or setting the schedule of workers. As such, everything related to remanufacturing could be realised reasonable, and the performance of the other factors could be higher if the organisation, planning, and control are carried out successfully. Compare with, for example, Subchapter 4.1 or the review of production planning and control for remanufacturing by Junior and Filho (2012).

4.2.2 REMANUFACTURING MARKET KNOWLEDGE

Creating a remanufactured product is only part of the task of realising remanufacturing business practices. As an element of the remanufacturing system, the sales process (Östlin, 2008) is critical to satisfying financial return requirements. Therefore, it could be beneficial to explore market demands before outputting new remanufactured products. Even though the corresponding new product has once been sold, it does not ensure that a remanufactured version will be sellable as well. Reasons like technological obsolescence (Kwak and Kim, 2015; Seitz and Peattie, 2004), poor perception of remanufactured products (Abbey et al., 2015b; Parker et al., 2015), and lack of knowledge of what remanufactured products are (Abbey et al., 2015a; Wang and Hazen, 2016) could influence the attractiveness of the products on the market. Even the chosen business model affects the sales patterns of remanufactured products, that is, how well the products are received by the market (Jensen et al., 2019).

Due to the perception and expectations of remanufactured products, the sales price tends to be lower than new products (Kabel et al., 2021; Sundin et al., 2016). Despite this, the cost reduction of remanufacturing, thanks to less consumption of energy and material in the process, can lead to keeping the level of profitability high (Östlin et al., 2008b). The lower price point also enables high-quality and premium brands to compete with low-cost competitors, thus potentially increasing the targeted customer segment (Atasu et al., 2008a). However, how accurately a remanufacturing offering is positioned in terms of, for example, volume, business model, and logistics channels determines the number of resources spent in relation to positive cash flows, that is, the economic benefit of remanufacturing.

4.2.3 REMANUFACTURING PROCESS IMPROVEMENTS

The remanufacturing process can be improved through various approaches, for example, disassembly strategies (Alfaro-Algaba and Ramirez, 2020; Bentaha et al., 2020), quality decisions (Cui et al., 2017), relationships between remanufacturing actors (Hong et al., 2015; Shi et al., 2016), and scheduling (Chen and Chang, 2012; Okuda et al., 2018; Reddy and Kumar, 2020). Similar to manufacturing, techniques such as the theory of constraints or inventory control can be applied to remanufacturing, but with additions due to the higher complexity and variability (Guide, 2000; Junior and Filho, 2012).

The higher the efficiency and effectiveness of a remanufacturing process, the more benefits that can be derived. Kurilova-Palisaitiene (2018) and Sundin (2006) showed this in practise when studying lean remanufacturing at several case companies. However, it is not certain that a specific improvement approach fits a particular investigated case (cf. Östlin and Ekholm, 2007; Pawlik et al., 2013; Seitz and Peattie, 2004). Another example is automated remanufacturing, as covered in Subchapter 4.1.1. Automation can be challenging but also, given the right circumstances, beneficial in terms of creating an efficient and effective process (Sakao and Sundin, 2019; Shahbazi et al., 2021).

4.2.4 DESIGN FOR REMANUFACTURING AND INFORMATION FEEDBACK

The design of products influences how efficiently the internal remanufacturing processes can be performed (Hatcher et al., 2011). For example, design for remanufacturing lowers the complexity of remanufacturing, thus also lowering labour requirements (Lundmark et al., 2009). However, since the design phase occurs at the first phase of the product life cycle, it is important to implement proper design measures from the beginning to counteract the occurrence of obstacles in the remanufacturing process (Lindahl and Sundin, 2013). Moreover, due to low initial product knowledge, it is difficult to reach a high understanding of future remanufacturing needs when designing products (Lindahl and Sundin, 2013). It is, therefore, important that the knowledge transfer channels between designers and remanufacturers are well developed (Doyle, 2011; Lindkvist Haziri et al., 2019).

Products designed for remanufacturing can provide further environmental (Kerr and Ryan, 2001) and economic (Sundin, 2004) benefits when undergoing remanufacturing compared to other products. However, despite these benefits, remanufactured products are seldom designed for the purpose (Kurilova-Palisaitiene et al., 2018). It could also be that manufacturing volumes tend to be higher than remanufacturing volumes, as such design for manufacturing is more preferred than design for remanufacturing; see Sundin (2001). As Hatcher et al. (2011) highlighted, another reason could be the gap between academic contributions and industry needs. They stated that complex models with high data requirements tend to be developed, which is incompatible with the data industries having access to during the design phase. This information could be more easily accessible if dedicated feedback channels from remanufacturing back to design are implemented (Lindkvist Haziri et al., 2019; Lindkvist Haziri and Sundin, 2019).

5 ECONOMIC ASSESSMENT OF REMANUFACTURING

The fifth chapter of this licentiate thesis provides an overview of how original equipment manufacturers can assess their profitability when evaluating the prospects of initiating profitable remanufacturing. The covered calculations are divided into three types, namely, general sales price calculations based on a cost structure, volume-dependent break-even calculations, and investment calculations based on net present value. The use of the calculations is showcased through seven scenarios based on the values of the case company. Finally, a comparison of the profitability of every scenario is presented.

In this chapter, the second research question is treated through the conducted economic assessment of the case company. It provides an initial answer to *RQ2. How can an initiation of OEM remanufacturing be assessed from an economic perspective?*

During the case study, the economic assessment was conducted in two steps at different project stages. The first was based on an NPV model that grasped the core aspects of a potential remanufacturing process within the case company's existent supply chain. This has been covered in Paper II. The second assessment had the same basis but took the analysis one step further with more precise data and inclusion of six centralised remanufacturing scenarios, where the remanufacturing facility is positioned nearby the case company's manufacturing plant, and one decentralised remanufacturing scenario, where the process is performed in several workshops in the retail network. Paper III describes this part of the study. The analysis was based on a break-even analysis to answer whether remanufacturing is profitable and, if so, what volume needs to be reached to create a stable and profitable remanufacturing process.

The underlying actors in the models are one remanufacturing facility, one distribution centre, several retailers, and product users, as depicted in Figure 10. Depending on a selected scenario, which flows that are active varies; compare with Table 10. Here, the remanufacturing facility is an OEM-managed site nearby the manufacturing plant. The distribution centre represents a point in the logistics chain where cores and products are, for example, batched together, inspected, redirected, or stored. The retailers represent the network of retailers that currently sell, service, and maintain products. At the retail sites, the remanufacturing process can also be performed in existing repair and service workshops with minor adjustments to equipment and layout. The customer acts as the supplier of cores and the purchaser of remanufactured products. It is assumed that the supply of cores and the demand for remanufactured products are sufficient from a modelling perspective.

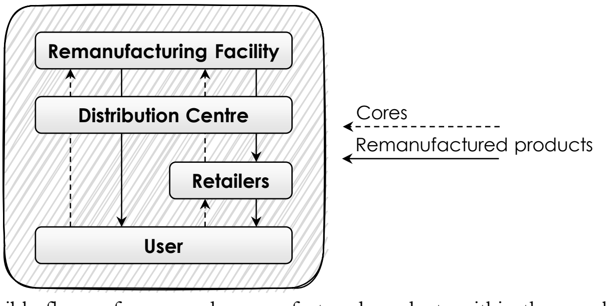

Figure 10. The actors and possible flows of cores and remanufactured products within the supply chain.

In total, seven scenarios have been developed. These are labelled as $\mathbb{A}$, $\mathbb{B}$, $\mathbb{C}$, $\mathbb{D}$, $\mathbb{E}$, $\mathbb{F}$, and $\mathbb{G}$. The main distinction between the scenarios is the actors responsible for core acquisition and sales of remanufactured products, as seen in Table 10. The remanufacturing actor is also altered. A decentralised scenario means that the remanufacturing process is performed at several retail sites concurrently; see Figure 10. Meanwhile, a centralised scenario implies that remanufacturing is performed at a single site managed by the OEM. Two of the Scenarios, $\mathbb{E}$ and $\mathbb{F}$, are tweaked more than the flows themselves. In Scenario $\mathbb{E}$, the retail margin on acquisition and sales is reduced to the same level as Scenario $\mathbb{G}$, assuming that the retailer and OEM are collaborating. In Scenario $\mathbb{F}$, the ownership of the product is kept by the OEM through a leasing contract, meaning that the buyback cost, as part of core acquisition, is neglected.

Table 10. Acquisition channels for cores and sales channels for remanufactured products for the centralised and decentralised Scenarios 𝔸 to 𝔾. The ● indicates an active flow, while the ○ indicates an active flow with a reduced margin.

	Type	OEM channel		Retail channel	
		Sales	Acquisition	Sales	Acquisition
𝔸	Centralised	●	●		
𝔹	Centralised	●			●
ℂ	Centralised		●	●	
𝔻	Centralised			●	●
𝔼	Centralised			○	○
𝔽	Centralised	●	Lease		
𝔾	Decentralised			●	●

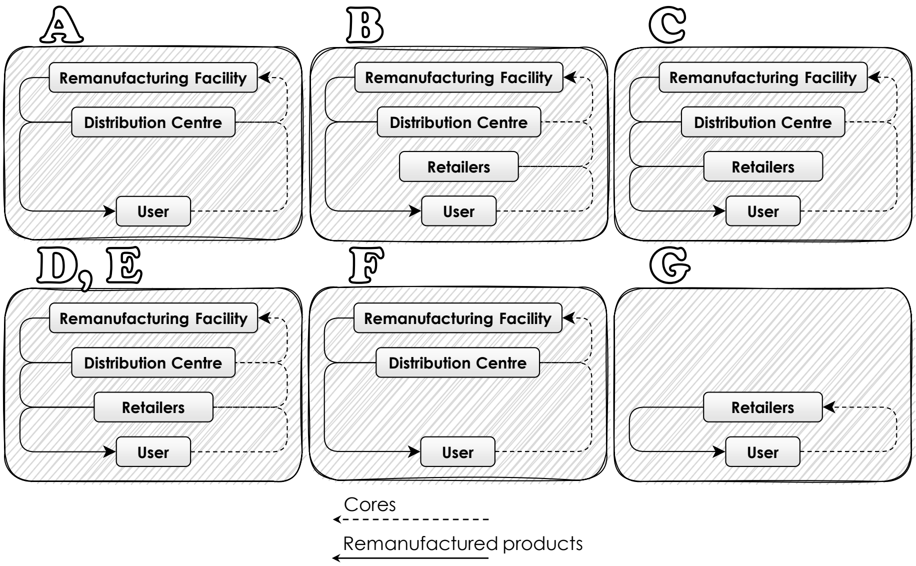

Figure 11. Schematic illustration of Scenarios 𝔸 to 𝔾.

The scenarios are modelled using the parameters listed in Table 11. Note that there is no cost for inventory handling included in the model. It is assumed that cores and finished products have little to no time in inventory, meaning that these costs are negligible. As the model targets an initiation of remanufacturing, the total volumes are on a low level compared to flows of active and new products. From that point of view, this assumption is expected to be insignificant as no additional costs arise using existing inventory solutions for new and serviced products. The model is designed based on available data during the conducted case study given certain conditions.

Hence, given other circumstances, tweaks of the model structure and parameters used might be needed.

Table 11. Descriptions of the parameters used for the two models.

Nomenclature	
C_C	Core acquisition cost
C_R	Cost of purchasing cores from another retailer
$C_{\%}$	Price reduction of remanufactured products compared to new
C_F	Fixed cost
C_{NEW}	Sales price of new products
D	Yearly workdays
F(Q)	Number of workers given quantity Q
F_t	Daily average workhours per worker
I_C	Investment cost
L_C	Labour cost per time unit
M	Profit margin, OEM
M_P	Additive profit margin, OEM
M_{PR}	Additive profit margin, retailer
M_{RAq}	Profit margin, retailer, on selling cores to OEM
M_{RSa}	Profit margin, retailer, on selling remanufactured products
n	Economic duration of an investment
P_C	Cost of parts and components for OEM
$P_{\rightarrow R}$	Cost of parts and components for retailers
Q	Daily remanufactured quantity
$S_{\%}$	Percentage of purchased cores that are scrapped
t	Remanufacturing process cycle time
$T_{\rightarrow RS,\ RS\rightarrow}$	Transport cost to (→RS) or from (RS→) remanufacturing site
T_C	Transport cost of cores to remanufacturing site and finished remanufactured products back to acquisition site
T_{OEM}	Transport cost that OEM covers for a retailer
T_R	Transport cost of cores to remanufacturing site from another retailer
VAT	Value added tax
W_C	Warranty claim cost
W_F	OEM warranty license fee

The calculation model is presented in the three subsequent chapters. The first covers sales price and margin for all scenarios; the second, the margin's dependability on the daily remanufactured quantity, Q; and the third, how the previous equations can be applied to an investment calculation scenario using NPV. The model is designed to output values per remanufactured unit or daily volume. As such, a total volume does not need to be calculated nor estimated, thus avoiding the uncertainty regarding the total produced volume while still gaining knowledge about its impact. The daily volume also allows scaling of the output depending on a periodically active remanufacturing process, such as acquiring cores during one part of the year and remanufacturing during the other. However, by doing so, scaling of the fixed cost is needed to allocate costs from outside of the active period.

5.1 SALES PRICE AND PROFIT MARGIN CALCULATIONS

In this subchapter, the calculations for Scenarios A to G are presented. Paper III published outputs and conclusions based on all seven scenarios, while Paper II primarily was based on the structure of Scenario G. Due to the overlap between the scenario calculations, explanations of certain parameters are covered only at the first occurrence to prevent repetitive redundancies. The calculation model is presented to output a sales price. However, as covered later in Subchapter 5.4, given a fixed sales price, a comparison is possible between the scenarios. To assess the profitability of each scenario, given a reasonable sales price, the profit margin is varied using M_P and M_{PR}. In cases where the sales price is not fixed, the calculations output the minimum sales price given the present costs and a selected common sales margin.

5.1.1 SCENARIO A – OEM ACQUISITION AND SALES

In Scenario A, the centralised remanufacturer manages the acquisition of cores from the users as well as the sales process of remanufactured products, as illustrated in Figure 12. The distribution centre is managed by the remanufacturer throughout all the presented scenarios. It acts as a hub where products can be batched and, in some cases, inspected. The distribution centre does not influence the presented equations but the value of the used parameters.

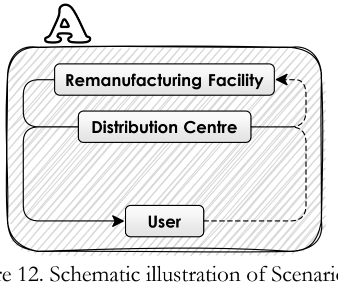

Figure 12. Schematic illustration of Scenario A.

The analysed product is primarily sold to private customers, meaning that value-added tax (VAT) is included in the price. Since the customer segments that remanufacturing often targets are price sensitive (Giutini and Gaudette, 2003; Subramanian and

Subramanyam, 2012; Sundin et al., 2016), adding the full VAT can have decremental effects on the total number of sales. During the study, the sales price of remanufactured and new products was considered when comparing the profitability of manufacturing and remanufacturing. This is why VAT has been included here, even though the tax does not directly affect the case company's profitability. The VAT perspective is of interest since remanufactured products are used products – or second-hand products – and, therefore, there are available legislative directives that allow for the reduction of VAT by deducting the cost of core acquisition from the value on which the VAT is calculated. The reduced VAT enables a lower tax level and thus a higher profit margin given a fixed sales price. On the European Union[1] and Swedish[2] levels, this principle is called the *margin scheme*. In the following equations, the principle has been applied where possible. The exclusion is in Scenario $\mathbb{F}$, where there is no cost of core acquisition to deduct due to leasing. In Eq. (1), the margin scheme is applied when calculating the sales price for products within Scenario $\mathbb{A}$. For simplicity reasons, it is assumed that the Swedish VAT level[2] at 25 percent is applied with a scaling factor of 0.8.

$$\text{Sales price} = \frac{C_C + L_C t + P_C + T_C}{1 - M} + M_P + 0.8\text{VAT}\left(\frac{C_C + L_C t + P_C + T_C}{1 - M} + M_P - C_C\right) \quad (1)$$

Given a value-added tax of 25 percent, Eq. (1) can be simplified to Eq. (2).

$$\text{Sales price} = 1.2\left(\frac{C_C + L_C t + P_C + T_C}{1 - M} + M_P\right) - 0.2C_C \quad (2)$$

In circumstances where the margin scheme cannot be used, for example, due to the purchase of cores from business-to-business customers, the same equation is written as follows in Eq. (3).

$$\text{Sales price} = \text{VAT}\left(\frac{C_C + L_C t + P_C + T_C}{1 - M} + M_P\right) \quad (3)$$

The core acquisition cost variable C_C can either be a set value or estimated through Eq. (4). In cases where non-remanufacturable cores are purchased, the linked cost is allocated to the total cost of cores through the variable $S_{\%}$, which proportionally increases the cost of core acquisition given a percental value of how many cores cannot be remanufactured.

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[1] Council Directive 2006/112/EC of 28 November 2006 on the common system of value-added tax. Ch. 4

[2] Mervärdesskattelag (1994:200) 9 a kap. (ML)

$$C_C = \frac{C_{NEW}C_{\%}}{(1 - S_{\%})} \quad (4)$$

Transport cost, T_C, handles both the cost of transporting cores to the remanufacturing site ($T_{\rightarrow RS}$) and finished remanufactured products back to the acquisition site ($T_{RS\rightarrow}$); see Eq. (5). The transport of parts is either assumed to be included in the cost of parts and components, P_C, or included in T_C.

$$T_C = T_{\rightarrow RS} + T_{RS\rightarrow} \quad (5)$$

5.1.2 Scenario B – Retail acquisition and OEM sales

The difference between Scenarios 𝔸 and 𝔹 lies in how the cost of core acquisition, C_C, is calculated, since retailers are involved in the core acquisition process; see Figure 13. The margin added by retailers for their involvement is represented by M_{RAq} as in Eq. (6). In the investigated case, there can be several retailers. However, this is not visible in the presented calculations as the expected inputs are based on an average retailer.

$$C_C = \frac{C_{NEW}C_{\%}}{(1 - S_{\%})(1 - M_{RAq})} \quad (6)$$

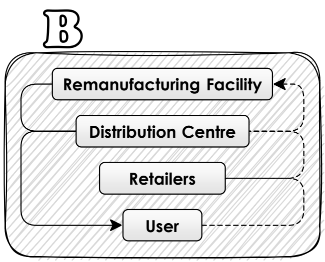

Figure 13. Schematic illustration of Scenario 𝔹.

5.1.3 Scenario C – OEM acquisition and retail sales

Compared to Scenario 𝔹, Scenario ℂ redirects the involvement of retailers to sales of remanufactured products instead of the acquisition of cores; see Figure 14. The retailer can profit from sales of the remanufactured products, as shown in Eq. (7). M_{RSa} is the retailer margin on sales of remanufactured products, and it is applied after the cost and margins of the centralised remanufacturer. Since the centralised remanufacturer acquires cores from the user, the cost of core acquisition is as in Eq. (4).

$$\text{Sales price} = 1.2\frac{\left(\frac{C_C + L_C t + P_C + T_C}{1 - M} + M_P\right)}{1 - M_{RSa}} - 0.2C_C \quad (7)$$

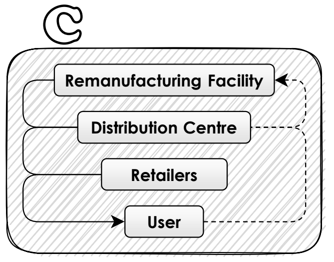

Figure 14. Schematic illustration of Scenario ℂ.

5.1.4 SCENARIOS D & E – RETAIL ACQUISITION AND SALES

To represent centralised remanufacturing but decentralised sales and acquisition processes, Scenario 𝔻 is used; see Figure 15. As the retail channels are already developed, utilising these for remanufactured products means that new channels do not need to be developed. However, by utilising retailers for forward and reverse flows, they can profit from both sales of remanufactured products, Eq. (7), and sales of cores, Eq. (6), meaning that the total margin of the retailer and the expected sales price will be high in comparison to other scenarios.

Therefore, Scenario 𝔼 is introduced. Here, the retailers' profit margin is halved, assuming that the OEM and the retailers have signed a collaboration agreement. The reduction by half sets the total margin of the retailers to a comparable level of the decentralised Scenario ℂ; see Eq. (8) and Eq. (9)[3]. Given other circumstances, the value of the divisor must be adjusted.

$$\text{Sales price} = 1.2\left(\frac{C_C + L_C t + P_C + T_C}{1 - M} + M_P\right)\left(\frac{1}{2} + \frac{1}{2(1 - M_{RSa})}\right) - 0.2C_C \tag{8}$$

$$C_C = \frac{C_{NEW}C_{\%}}{(1 - S_{\%})}\left(\frac{1}{2} + \frac{1}{2\big(1 - M_{RAq}\big)}\right) \tag{9}$$

[3] For legibility, $C_C = \frac{C_{NEW}C_{\%}}{(1 - S_{\%})} + \frac{\frac{C_{NEW}C_{\%}}{(1 - S_{\%})(1 - M_{RAq})} - \frac{C_{NEW}C_{\%}}{(1 - S_{\%})}}{2} = \frac{C_{NEW}C_{\%}}{(1 - S_{\%})}\left(\frac{1}{2} + \frac{1}{2\big(1 - M_{RAq}\big)}\right)$

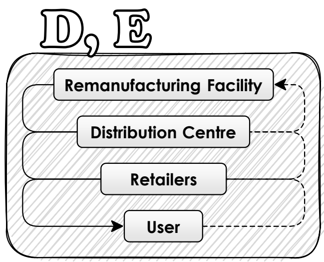

Figure 15. Schematic illustration of Scenarios $\mathbb{D}$ & $\mathbb{E}$.

5.1.5 SCENARIO F – OEM ACQUISITION AND SALES

In Scenario $\mathbb{F}$, another type of business model influences how cores are returned, namely leasing. The scenario follows the same flow patterns as Scenario $\mathbb{A}$; see Figure 16. As such, the remanufacturer has kept the ownership of the core and does not have to purchase it from the user. The cost of core acquisition, C_C, is therefore redacted. For comparability reasons, it is assumed that the remanufactured product is sold through a traditional one-of-sale to output a single sales price; see Eq. (10). Based on the needs of the case company, it is also assumed that retailers are not involved at all, as leasing enables an increased control of the product over its life cycle. Moreover, VAT with a margin scheme is not applied either, as there are no core acquisition costs to take into account.

$$\text{Sales price} = \text{VAT}\left(\frac{L_C t + P_C + T_C}{1 - M} + M_P\right) \tag{10}$$

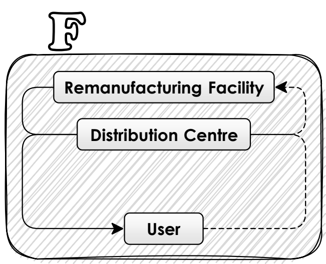

Figure 16. Schematic illustration of Scenario $\mathbb{F}$.

5.1.6 SCENARIO G – RETAIL ACQUISITION AND SALES

In Scenario $\mathbb{G}$, as the only decentralised scenario, there is no direct gain for the OEM from the remanufacturing process; see Figure 17. The OEM only profits indirectly from the sales of spare parts. As some retailers are provided free-of-charge transports, the OEM profit in Eq. (14) is reduced by the corresponding amount, T_{OEM}. The OEM covers warranty for certified products, hence the reason for both warranty fee, W_F, and warranty cost, W_C. For comparability reasons, these parameters could be added to other equations as well, for example, Eq. (8). Here, they are only added to Scenario 𝔾 since there was a request during the case study to have such parameters added.

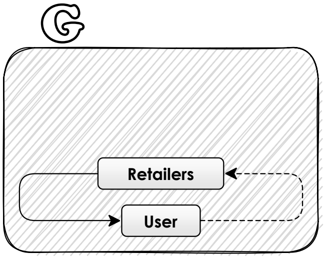

Figure 17. Schematic illustration of Scenario 𝔾.

For the customers to receive an equivalent product from every scenario, the OEM offers a warranty licence fee that the remanufacturing retailers can pay to be covered by a certified OEM warranty; cf. Ijomah (2002) and Sundin et al. (2016). From the point of view of the OEM, the cost of warranty claims, W_C, and the warranty licence fee, W_F, cancel out, meaning that the OEM does not benefit from providing the license. Since warranty claims are an uncertain process but assumed to be consistent between the centralised remanufacturing Scenarios 𝔸 to 𝔽, it has been left out. From the OEM perspective regarding the warranty, all scenarios are therefore comparable.

Cores could be sourced from other retailers, which induces an additional core purchasing cost, C_R, and a transport cost, T_R. Similar to how multiple retailers could source cores in the centralised remanufacturing scenarios, retailers capable of remanufacturing can source cores from less capable retailers. Note that the parts cost, P_C, does not have the same value as in the centralised scenarios, and there is no cost for scrapped cores, $S_{\%}$; see Eq. (12). There is no cost for scrapped cores for two reasons. Firstly, it is assumed that all cores are inspected thoroughly at the remanufacturing location before any purchase, and non-remanufacturable cores are returned to the product owner. A product with an OEM certified warranty also has a recommended sales price to follow, meaning that retailers need to ensure that the number of scrapped purchased cores is low. Secondly, the view here is primarily from the perspective of the OEM. As such, the profitability of the OEM is not affected by a high scrap rate at a retailer; see Eq. (14).

$$\text{Sales price} = 1.2\left(\frac{C_C + L_C t + P_{\rightarrow R} + T_C + W_F}{1 - M_{RSa}} + M_{PR}\right) - 0.2C_C \tag{11}$$

$$C_C = C_{NEW}C_{\%} + C_R \tag{12}$$

$$T_C = T_{\rightarrow RS} + T_{RS\rightarrow} + T_R - T_{OEM} \tag{13}$$

The profit of the OEM is provided by Eq. (14).

$$M_P = P_{\rightarrow R} - P_C + W_F - W_C - T_{OEM} \tag{14}$$

5.2 Profitability dependent on volume

This subchapter presents equations that determine the profitability with the varied throughput rate of the remanufacturing process. The calculations are designed to be used as add-ons to the preceding equations from Subchapter 5.1.

5.2.1 Exemplified with Scenario A

As the potential volume of the remanufacturing system is unknown, it is interesting to know how the profit margin depends on the volume. This will show what volume needs to be reached to become profitable for each scenario, given a fixed cost, C_F. For simplicity reasons, the focus is on a daily volume, from which profitability can be derived for other periods.

The margin presented here is the difference between revenue and cost (Eq. 15); the focus is on a monetary value instead of a percental. As an example, the equations for Scenario Ⓐ are provided. For the other scenarios, similar equations can be derived based on their counterparts in Subchapter 5.1.

$$\text{Margin} = \text{Revenue} - \text{Cost} \tag{15}$$

The revenue corresponds to the value given by Eq. (2), (7), and (8), depending on the scenario, but without VAT. The revenue for Scenario Ⓖ, Eq. (11), is covered in Subchapter 5.2.2 as a special case. The revenue could also be a set value; then, there is no need for an estimation. The margin parameters M_P and M_{PR} are used to keep the sales price constant. For Scenario Ⓐ, Eq. (16) is used.

$$\text{Revenue} = Q\left(\frac{C_C + L_C t + P_C + T_C}{1 - M} + M_P\right) \tag{16}$$

On the other hand, the cost is dependent directly on the quantity, Q, as the number of full-time workers, F, depends on Q. Therefore, F(Q) is introduced. Every full-time worker, F(Q), works a set number of hours every day, F_t, and every day there is a fixed cost, C_F.

$$F(Q) = \left\lceil \frac{Qt}{F_t} \right\rceil \tag{17}$$

$$\text{Cost} = F(Q)L_C F_t + Q(C_C + P_C + T_C) + C_F \tag{18}$$

Thus, Eq. (15), (16), (17), and (18) imply Eq. (19).

$$\frac{\text{Margin}}{\text{unit}} = \frac{Q\left(\frac{C_C + L_C t + P_C + T_C}{1 - M} + M_P\right) - F(Q)L_C F_t - Q(C_C + P_C + T_C) - C_F}{Q} \tag{19}$$

These can be simplified to Eq. (20).

$$\frac{\text{Margin}}{\text{unit}} = \frac{C_C + L_C t + P_C + T_C}{1 - M} + M_P - \frac{F(Q)L_C F_t + C_F}{Q} - C_C - P_C - T_C \tag{20}$$

This shows that only the fixed cost, $C_{F,}$ significantly affects the margin per unit. Note that F(Q) has a slight alternating effect due to being rounded to an integer as in Eq. (17).

5.2.2 Exemplified with Scenario G

Being a decentralised scenario, the OEM's profitability per product is independent of the total quantity, as shown in Eq. (21). However, in a practical case, it is likely that even the decentralised scenario is somewhat dependent on the throughput rate of the process, the reason being, for example, that it is easier to achieve low transport cost per unit if the total quantity is high and consistent. Observe that Eq. (21) does not consider retailer's profitability.

$$\frac{\text{Margin}}{\text{unit}} = Q\frac{P_{\rightarrow R} - P_{OEM} + W_F - W_C - T_{OEM}}{Q} = P_{\rightarrow R} - P_{OEM} + W_F - W_C - T_{OEM} \tag{21}$$

5.3 Net present value

Initiating remanufacturing in practice requires consideration of investment costs as well as assessing whether the investment would pay itself off. This has also been elaborated on in Paper II. To target this challenge, an NPV model was derived. NPV presents whether an investment is profitable by discounting future cash flows – revenues and costs – to a present monetary value. Here, it is assumed that n is the yearly economic duration of the investment, while r is the discount rate. The rule of thumb is that an investment, $I_{C,}$ is worth proceeding with if the NPV is positive, and when comparing several NPVs with duration n, the investment with the highest NPV is considered the most profitable.

Since the NPV calculations are similar to the scenarios covered in Subchapter 5.2, only Scenarios A and G are listed below. These two scenarios cover the main characteristics of all scenarios.

5.3.1 Net present value exemplified with scenario A

As the initial step of the remanufacturing NPV calculation, Eq. (22) is used (cf. Anupindi et al., 2012).

$$\mathrm{NPV} = -I_C + \sum_{i=1}^{n} \frac{\mathrm{Revenue}_i - \mathrm{Cost}_i}{(1 + r)^i} \tag{22}$$

By applying Eq. (16) and (18) to Eq. (22), Eq. (23) is obtained. The equation shows the case study-specific parameters used in the assessment of remanufacturing.

$$\mathrm{NPV} = -I_C + \sum_{i=1}^{n} \frac{D_i \left(Q\left(\frac{C_C + L_C t + P_C + T_C}{1 - M} + M_P\right) - F(Q)L_C F_t - Q(C_C + P_C + T_C) - C_F\right)_i}{(1 + r)^i} \tag{23}$$

By assuming that $\mathrm{Revenue}_i$ and Cost_i are constant for every year i, Eq. (23) is simplified to Eq. (24).

$$\mathrm{NPV} = -I_C + D\frac{1 - (1 + r)^{-n}}{r}\left(Q\left(\frac{C_C + L_C t + P_C + T_C}{1 - M} + M_P\right) - F(Q)L_C F_t - Q(C_C + P_C + T_C) - C_F\right) \tag{24}$$

5.3.2 NET PRESENT VALUE EXEMPLIFIED WITH SCENARIO G

As covered earlier, the primary focus is on profitability from the OEM's point of view. To derive an NPV equation for Scenario Ⓖ, Eq. (14) is used to represent both $\mathrm{Revenue}_i$ and Cost_i for Eq. (25). Naturally, the NPV of the retailers needs to be positive as well. Paper II showed that the retailer NPV was positive given the current circumstances. This is further elaborated on in Subchapter 5.4.

$$\mathrm{NPV} = -I_C + \sum_{i=1}^{n} D_i(P_{\to R} - P_{OEM} + W_F - W_C - T_{OEM})_i \tag{25}$$

Eq. (25) can be simplified like Eq. (24), given the same constants.

$$\mathrm{NPV} = -I_C + D\frac{1 - (1 + r)^{-n}}{r}(P_{\to R} - P_{OEM} + W_F - W_C - T_{OEM}) \tag{26}$$

5.4 CASE STUDY RESULTS

When applying the equations from above, sales price per unit as well as revenue, profit margin value, and cost structure were received. The specific values based on the case company have been retracted. Despite this, the profitability ratio between the seven scenarios is depicted in Figure 18. Here, for comparability reasons, the sales price of all seven scenarios is set to a common value by adjusting the additive profit margins, M_P and M_{PR}. The figure also includes two selected scrap rates that showcase the influence the scrap rate has on the profitability of the OEM. In a case where the inspection process, or other circumstances, prevent the purchase of non-remanufacturable cores, that is, no scrapped cores, all centralised scenarios are more beneficial than the decentralised Scenario Ⓖ. However, there are also other influencing factors present which are discussed on a higher level than the indications of the numeric values.

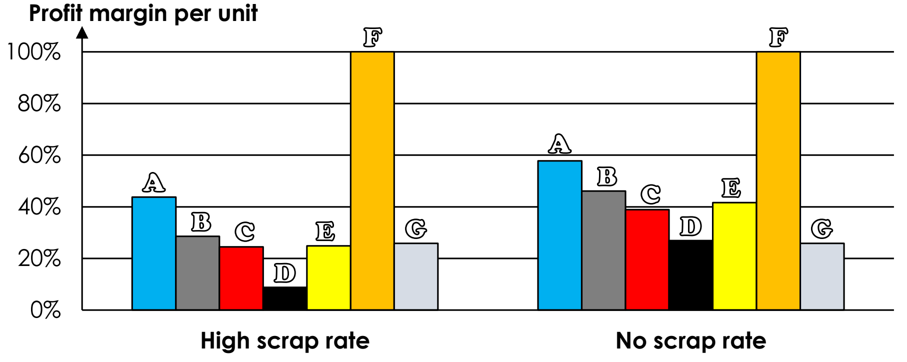

Figure 18. Profitability ratio between Scenarios A to G given high and no scrap rate. Based on Vogt Duberg et al. (2021) in Paper III.

Scenarios F and G are, as described in Subchapter 5.1, unaffected by the scrap rate since the acquisition cost is either set to zero or core acquisition decisions of retailers do not influence the OEM. What is interesting to note in Figure 18 is the difference between Scenario F and the other scenarios. The acquisition cost has a significant impact on profitability. For the given circumstances, a business model where the ownership is kept by the OEM or the remanufacturer, or both, is therefore preferable. However, it also sets high requirements for realising such procedures. These are requirements that the case company had low experience in during the study. There are, therefore, other barriers to consider regarding the numeric values to reach, for example, a full-fledged PSS.

The values shown in Figure 18 showcase an ideal case where the highest possible profit margin is highlighted. In reality, the cost structure is also affected by a high fixed cost whose impact on the total cost per unit is dependent on the total remanufacturing volume. This dependability is shown in Figure 19. The figure is based on the equations presented in Subchapter 5.2. As previously described, the values are based on a daily volume to easily scale the model to fit a periodically active remanufacturing process. However, the preference between daily volume or a general volume does not affect the pattern or relation of the curves. It is also easier to grasp a daily throughput rate and put it into perspective than an arbitrary volume.

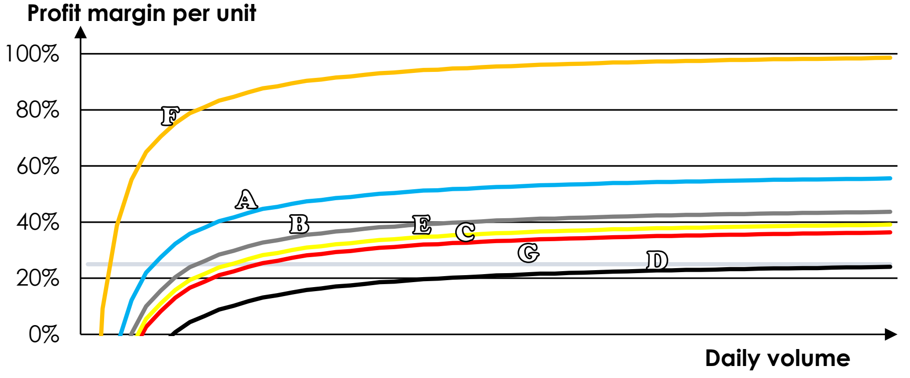

Figure 19. Profitability ratio between Scenarios 𝔸 to 𝔾 with varied daily volume and no scrap rate. Based on Vogt Duberg et al. (2021) in Paper III.

At a profit margin per unit of zero percent, the break-even point has been reached; compare Figure 4 in Subchapter 2.3.2. Since the OEM does not have influence over the remanufacturing process in Scenario 𝔾, there is no fixed cost to consider. The break-even point is therefore instant. For the other scenarios, the break-even point is reached at various volumes in the order: Scenario 𝔽 - 𝔸 - 𝔹 - 𝔼 - ℂ - 𝔻. The peak of each curve goes towards the no scrap rate values in Figure 18. It is, therefore, clear that Scenario 𝔻 – centralised remanufacturing with retailer core acquisition and sales of remanufactured products – is not a valid alternative as it barely beats Scenario 𝔾 when there is no scrap rate.

If a high scrap rate is expected, it is most beneficial for the OEM to either focus on Scenario 𝔸 or Scenario 𝔾. Scenario 𝔾 is a low-risk approach since the current sales channels through existing retailers can be kept and utilised. The retailers also have an established customer communication network that can be utilised to acquire cores. On the other hand, Scenario 𝔸 has the potential to be more profitable, but due to no established way of contacting current product owners or users and without an established independent sales channel, it is difficult to realise the scenario in practice without trialling with any of the other scenarios beforehand.

At a low scrap rate, the centralised scenarios outperform Scenario 𝔾, except for Scenario 𝔻. However, the argument holds that the retailers are currently in the power position of having the ability to acquire cores more easily and, therefore, also more easily reach high and profitable remanufacturing volumes. The centralised Scenarios 𝔹, 𝔻, and 𝔼 with retail core acquisition are therefore likely to reach a higher daily volume than the other scenarios, meaning that the order of the break-even volume does not necessarily imply an order of highest profitability. The same argument can be used when comparing centralised and decentralised remanufacturing. Being responsible for the remanufacturing process could mean that the retailers are more eager to acquire cores, thus initially leading to higher volumes. This effect is further enforced when investment costs are included using the NPV calculations in Subchapter 5.3, as a centralised remanufacturing scenario directly induces an OEM cost, which decentralised does not. However, long-term, once the acquisition and scaling obstacles have been overcome and the OEM processes have matured, it is likely that centralised remanufacturing will reach the same volumes, leading to higher profitability for the OEM thanks to the economies of scale and fewer middle hands. The patterns seen during the case study are showcased in Figure 20.

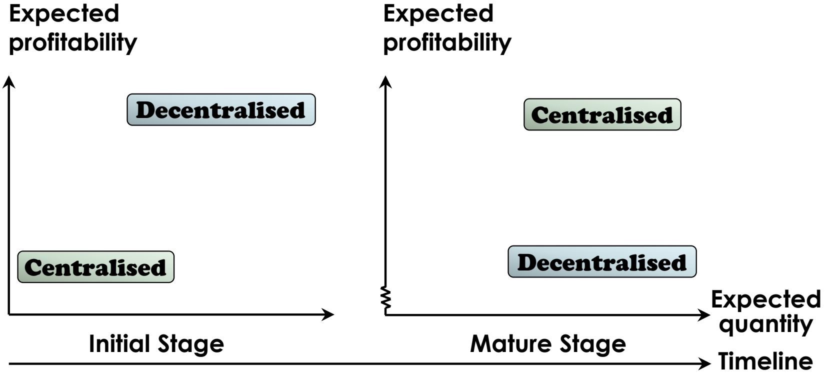

Figure 20. Comparison between centralised and decentralised remanufacturing processes during two different matureness stages with consideration to the case OEM profitability and produced quantity.

6 DISCUSSION

The sixth chapter of this licentiate thesis discusses how the prerequisite factors for OEM remanufacturing can be applied together with an economic assessment of initiating remanufacturing. That is, a discussion related to the aim of the thesis and the interaction between the two research questions. When answering the two research questions, a five-step approach for initiating remanufacturing is proposed. Further, the chosen research method is covered from the view of suitability and results impact, as well as limitations and generalisability of the research.

6.1 INTERACTION BETWEEN THE PREREQUISITES AND THE ECONOMIC ASSESSMENT

The following discussion is led by the aim of this thesis: *to explore how original equipment manufacturers can initiate profitable remanufacturing*. As presented in Chapters 4 and 5, the research contribution touches upon the topic through two perspectives, namely prerequisites of OEM remanufacturing and an exemplified economic assessment of remanufacturing. The derived essential prerequisite factors aim to increase the understanding of how the fundamental building blocks of remanufacturing could be identified for OEMs interested in exploring their remanufacturing prospects and initiating profitable remanufacturing. The essential prerequisite factors answer to the question: *what is needed?* By creating *the remanufacturing rocket*, the curiosity of the practitioners and scholars is targeted with hopes of inspiring to action as well as creating a memorable concept: one that can be brought up when remanufacturing opportunities appear.

In an ideal world, all manufactured products are subject to remanufacturing. However, today, the remanufacturing market is only a few percent compared to manufacturing (Parker et al., 2015; USITC, 2012), meaning many remanufacturing prospects are not utilised. For OEMs, there could be hindering factors such as their focus on selling new products or fear of product cannibalisation (Matsumoto and Umeda, 2011). But there are signs that such obstacles are overcome since the remanufacturing industry is growing; for example, the European Remanufacturing Network estimated that remanufacturing could potentially triple in size from 2015 to 2030 (Parker et al., 2015). The shift towards circular operations, however, can only occur if the conditions are right (De Jesus and Mendonça, 2018; Kirchherr et al., 2018). One critical aspect is the remanufacturing know-how (Barquet et al., 2013). This perspective is touched upon in answering the first research question, where prerequisite factors for initiating OEM remanufacturing are identified.

However, solely identifying the building blocks is not a sufficient basis for decision-making since remanufacturing needs to be viewed in a larger context of how it affects the current operations in companies long-term (van Loon and Van Wassenhove, 2020). The competitiveness of companies is influenced by their ability to turn resources into positive cash flows and thereby create profitable business opportunities (Gallo et al., 2012; Porter, 1998). Therefore, an economic assessment is valuable to decide whether remanufacturing is worth initiating. The earlier the assessment is conducted, the less resources are potentially spent in vain. However, the other side of the coin is that early economic assessments could mean fewer insights to consider. Hence, this influences the accuracy and results of the economic assessment. The models in Chapter 5 exemplify how an early economic assessment could be laid out.

Before conducting an economic assessment to answer the question of whether remanufacturing is worthwhile from a profitability perspective, an initial plan or understanding of remanufacturing must be developed. Otherwise, it is difficult to target remanufacturing successfully (Barquet et al., 2013). Here, the remanufacturing prerequisite factors are proposed to build up the basis for an economic assessment. Based on the presented research, when OEMs are looking into initiating remanufacturing, it is proposed to iteratively view the essential prerequisite factors and conduct the economic assessment, and then let the two aspects build upon each other to create a stable remanufacturing foundation to stand on before proceeding with further refinements.

By thereafter applying the supporting prerequisite factors, a similar iterative approach is enabled with the economic assessment. The supporting prerequisite factors answer the question: *How to improve?* As such, the parameters of the economic assessment are influenced by the prerequisite factors, and the decision regarding how the remanufacturing system should be designed is based on the influences of the results of the economic assessment. The iterative approach is depicted in Figure 21.

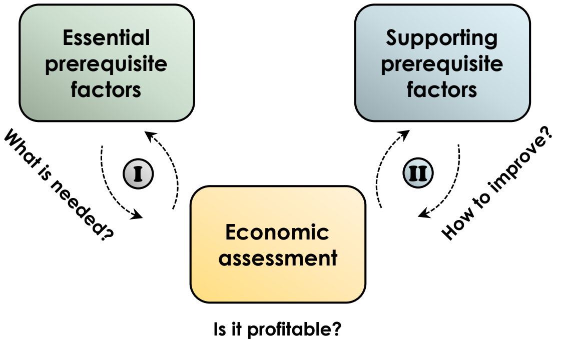

Figure 21. Interaction between the essential and supporting prerequisite factors and the economic assessment of remanufacturing in an iterative two-stage approach.

The results of the NPV and break-even models exemplify how an economic assessment can be used to gain arguments for initiating remanufacturing. However, the applicability of the models to a generic company has not been assessed, meaning that there could be a lack of generalisability. The economic assessment through the case study shows one case-specific example for an electronic and electrical equipment OEM, but the underlying structure of how a remanufacturing initiation could be approached is generic within the study boundaries – see the delimitations in Subchapter 1.3 – by adding to, adjusting, or replacing the models to fit cases beyond the scope of this study. For other examples of economic assessment methods, the reader is advised to further reading; see, for example, Junior and Filho (2012), Goodall et al. (2014), and Rizova et al. (2020).

The prerequisite factors are more general than the exemplified economic assessment as they are defined primarily in theory while being inspired by practice. The idea is to influence the user to think in a certain way rather than provide a definitive answer to what all the important considerations are. Once the fundamental concepts are understood – for example, core accessibility, process steps, location, and worker needs – parallels could be drawn between the factors, thus creating a case-specific understanding of the remanufacturing prospects. With the said approach, the prerequisite factors can be applied without major adjustments in a wider range of remanufacturing scenarios.

To use the proposed approach in Figure 21 for a remanufacturing initiation and to assess the economic performance, there are more steps required. Based on the case study, it is proposed to first identify a product family that could be a subject for remanufacturing. Selecting a product family instead of a single product is more suitable since multiple similar products may be evaluated simultaneously to find the best fit. Later in the process, a further refinement of the product selection could be performed. Afterwards, based on the selected product family, relevant actors within and outside of the OEM should be involved in the remanufacturing initiation approach. This step is relevant for several reasons, for example, for data collection purposes, but more importantly, to get approval and inputs from all areas affected by remanufacturing. This helps in developing remanufacturing that does not disturb existing operations more than necessary.

Once these aspects are set, the third step, the iterative approach to determine the prerequisite factors and conduct the economic assessment, should be performed. Here, all the insights for confident decision-making are derived. Developing a plan to initiate remanufacturing follows as the fourth step. Finally, once remanufacturing is set up and running, the final results should be compared with the insights and assessments of the third step. Based on deviations, the assessment methods can be refined and validated and used further on other product types.

The proposed five-step approach to initiate remanufacturing is, therefore:

Step 1. Select a product family
Step 2. Involve actors prone to be impacted by remanufacturing
Step 3. Iteratively identify prerequisites and assess economic performance
Step 4. Develop a plan and initiate remanufacturing
Step 5. Refine and validate the assessment in Step 3

By applying the approach, OEMs are able to initiate remanufacturing based on economic factors. However, the economic assessment, as exemplified in this thesis, is not definitive. The conducted assessment goes beyond the numeric values and highlights challenges on a higher level, such as the impact of retailer involvement and the importance of reaching sustainable volumes. When conducting an economic assessment, product types and company characteristics highly influence the suitability of various economic assessment methods (van Loon and Van Wassenhove, 2020). Therefore, when initiating remanufacturing, one should carefully take that into consideration. For other examples, assessment models highlighted in the reviews by Goodall et al. (2014) and Rizova et al. (2020) are recommended for inspiration.

6.2 ANSWERS TO THE RESEARCH QUESTIONS

RQ1. What prerequisites are needed when initiating original equipment manufacturer remanufacturing?

The case study research, alongside the literature review, provided the environment to answer the first research question. The outcome was eight prerequisite factors for initiating OEM remanufacturing. These factors were further divided into essential and supporting prerequisite factors and presented as *the remanufacturing rocket*; see Figure 22. The essential factors are requirements for remanufacturing, while the supporting factors enhance its performance.

The two sets of factors provide building blocks of the requirements of OEMs when initiating remanufacturing. As such, they play a role in developing initial know-how, that is, the knowledge needed to initiate remanufacturing. While the definition of the factors has been exemplified in Chapter 4, the primary contribution is the essence of how the prerequisite factors are defined for companies. It is important to note that when applying the factors in practise, they need to be viewed from the perspective of the given circumstances. This is due to the case-specific uniqueness of companies and products, which influences the exact needs. The prerequisite factors can inspire an understanding of how remanufacturing can be initiated.

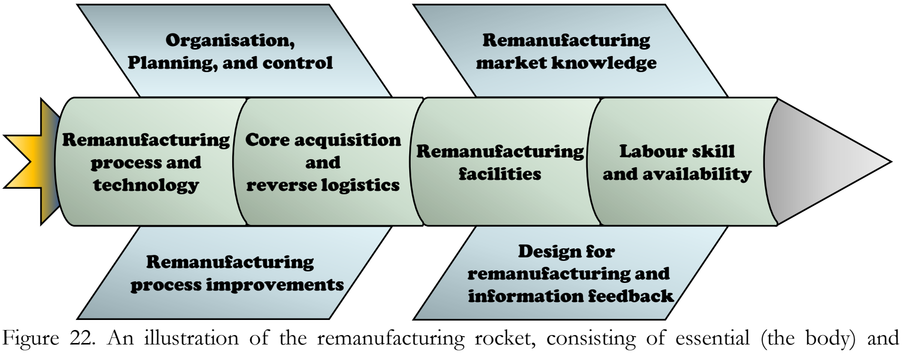

Figure 22. An illustration of the remanufacturing rocket, consisting of essential (the body) and supporting (the wings) factors that together enable successful remanufacturing. Based on Vogt Duberg et al. (2020) in Paper I.

RQ2. How can an initiation of original equipment manufacturer remanufacturing be assessed from an economic perspective?

This thesis developed two analytical remanufacturing models with a basis in NPV and break-even analysis. The NPV model viewed the remanufacturing system from an investment perspective, while the break-even model focused on identifying the threshold volume where remanufacturing could be seen as reasonable in terms of risktaking and profitability; see Chapter 5. There were seven primary scenarios developed considering centralised and decentralised remanufacturing involving the case company and its retail network. The scenarios provided the models with an extended sensitivity analysis, which allowed us to study, compare, and rank several alternative approaches to how remanufacturing could be performed at the case company.

The models exemplified how a remanufacturing initiation could be economically assessed. However, its applicability to a generic company has not been assessed. Instead, in terms of generalisability, the focus is on linking an economic assessment with the prerequisite factors. Here, an iterative process was suggested where, first, the essential prerequisite factors were identified upon which an economic assessment was performed. Based on the assessment, refinements to the essential factors are possible. This process continues in a finite loop before a similar iterative process is initiated between the supporting prerequisite factors and the economic assessment. The primary contribution is the exemplification of how an economic assessment can be applied to a decision of whether remanufacturing is worth initiating. The iterative process is part of a proposed *five-step approach for initiating remanufacturing* (5AFIR), as depicted in Figure 23.

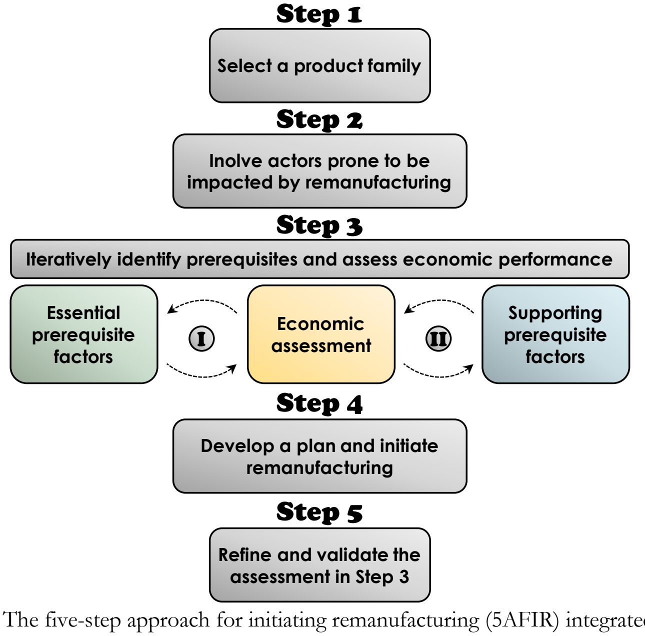

Figure 23. The five-step approach for initiating remanufacturing (5AFIR) integrated with the interaction between the economic assessment of remanufacturing and the essential and supporting prerequisite factors.

6.3 INFLUENCE OF THE CHOSEN RESEARCH METHOD ON THE RESULTS

The present research has applied a case study research method together with an economic assessment of a prospectively remanufacturing initiation at the case company. There are alternative research methods that could have been used to target the designated research questions: two examples are action research and interactive research. These methods allow for an in-depth and hands-on implementation or development of processes in practice (Säfsten and Gustavsson, 2020). Case study research has less focus on action than these but more emphasis on studying a contemporary phenomenon (Yin, 2018). The conducted case study has mapped the case company's prospects for remanufacturing by retrieving and processing how remanufacturing could be incorporated into existing operations. Based on that, the material was then put into a model to assess the economic feasibility of the findings.

The principle is also doable in a more action-based setting. Consider the scenario where action or interactive research implements remanufacturing in practice. In that case, a further understanding of the remanufacturing system would be gained, and a more detailed and accurate economic model could have been built. It would have influenced the recommendations to the case company. However, as stated in the discussion, the importance lies in presenting an approach to how remanufacturing could be assessed from an economic point of view. Therefore, studying the progress of initiating remanufacturing through a case study is preferable compared to studying an implementation through action or interactive research. The target audience of the chosen economic model might also change due to the case-specific applicability of the model.

The identified prerequisite factors are not likely to change based on the chosen research method but rather on the data collection methods. Instead of a literature review, another suitable method is surveys. The approach moves the foci from drawing conclusions from previous research to empirical data. The survey would suggestively target industry experts at remanufacturing firms to identify essential and supporting prerequisites or even factors of another structure. Naturally, this would alter the point of view of the research and influence the research results. Nonetheless, the chosen approach based on single case study data and reliance on a literature review to create the factors seem reasonable as a literature review more comprehensively creates general results. The single case study ensured that the derived factors also made sense in a practical scenario.

With these statements, selecting another research method or data collection method will likely influence the research findings. However, due to the nature of the research area, this is perceived as a non-issue. The reason is that there are no definitive rights and wrongs as long as the intention of the research and the findings are transparent and reasonable according to established methods (Säfsten and Gustavsson, 2020). As such, another study with the same aim and research questions will likely lead to other findings, but unlikely findings that contradict the results of the conducted research.

As with all research, there are limitations in this research as well. For example, to increase the generalisability of the research, further case study companies and target products (not only electronic and electrical equipment) could have been incorporated. The economic assessment only showcases two complementary approaches, NPV and break-even, and the methods are influenced by the characteristics and needs of a single case company. It is, therefore, not possible to view the results as generically applicable. There is also no information given on when the economic models can be applied to other cases; such decisions are left for the users to investigate. Furthermore, continuous improvements are always possible (Pettersen, 2009). Simultaneously, research results need to be published, meaning that a finite endpoint needs to be set. In that regard, further refinements and extension to the research are possible and will be further covered in Subchapter 7.3.

7 CONCLUSIONS

The seventh chapter of this licentiate thesis describes how the aim has been met. The chapter also portrays how the research study positively contributes to academia and industry. The thesis is finalised with prospects for future research.

The aim of this thesis – *to explore how original equipment manufacturers can initiate profitable remanufacturing* – was targeted with a basis in a case study when exploring the prospects of how an OEM – the case company – could transition from solely being a manufacturer of new products to also a provider of remanufactured products. The research contribution consists of two concepts: *the remanufacturing rocket* and *the remanufacturing 5AFIR*. Together, these two concepts can guide OEMs to initiate profitable remanufacturing. The remanufacturing rocket lists the required building blocks for initiating remanufacturing through essential and supporting prerequisite factors. Meanwhile, the profitability of remanufacturing is ensured through an economic assessment that relies on the prerequisite factors. As part of the remanufacturing 5AFIR, where a five-step approach for initiating remanufacturing is proposed, the prerequisite factors are derived iteratively in relation to an economic assessment. This scientific contribution has value for both academia and industry. That value is presented in the following subchapters.

7.1 CONTRIBUTION TO ACADEMIA

The research study builds upon the cumulative body of knowledge within the remanufacturing area by exploring the characteristics of initiating remanufacturing. The scientific contribution is multifaceted. On the one hand, the prerequisite factors for OEM remanufacturing advance the research area on prerequisites of remanufacturing and aid other scholars in conceptualising the foundation of remanufacturing. It can be used for several instances, for example, creating a theoretic basis when modelling remanufacturing system processes or extending the research area on how manufacturers can successfully transition into becoming remanufacturers.

The proposed *five-step approach to initiate remanufacturing* (5AFIR), together with the remanufacturing prerequisite factors and the exemplified economic assessment, show how other researchers can conduct research on companies in the phase where initiating remanufacturing could be interesting. By researching various aspects of remanufacturing initiation, there are hopes of growing the number of remanufacturers on the market. From this, there are societal gains primarily in the environmental and economic areas. Moreover, from an academic perspective, a higher number of remanufacturing industries means more potential study objects. Therefore, research on remanufacturing does not only have academic value but also value in the industry.

7.2 CONTRIBUTION TO INDUSTRY

Most companies have a strong focus on profitability, and by showcasing how remanufacturing can be assessed from an economic perspective, their interest in remanufacturing could be ignited. Long term, by conducting this research study, there are hopes to stimulate the growth of remanufacturing operations in OEMs and other industries. The research study exemplifies how practitioners can assess their prospects to initiate profitable remanufacturing. The developed remanufacturing prerequisites, as part of the *five-step approach to initiate remanufacturing* (5AFIR), can give practitioners an initial view of how they can target the circular and fundamental parts of remanufacturing and provide an understanding of how they can initiate their journey towards profitable remanufacturing practices.

If the long-term goals succeed in increasing the number of remanufacturers, further research can also be stimulated. For example, research on effective and efficient remanufacturing processes or other improvement processes can hopefully, in addition to research on remanufacturing initiation, lead to remanufacturing processes reaching top-level economic, environmental, and social benefits for society.

There has also been a contribution made to the case company. Before the start of the research study, it had no experience in remanufacturing, and there were no insights on how remanufacturing could be performed or whether it could be profitable. By conducting this research, as presented in this licentiate thesis, the case company has gained new insights about remanufacturing and its prospects of initiating profitable remanufacturing. At the end of the research study, the case company had several possible initiation alternatives to choose from, each with a set of deliverables and challenges. Ultimately, the case company now has the needed insights to decide whether remanufacturing is the path they would like to pursue.

7.3 FUTURE RESEARCH

The research opens opportunities for further research in initiating remanufacturing. Since one product type or one company is not like another, there is a need for a continuation of the work. As of now, one view has been presented from which other scholars can take a stand. For the same reason, there is also a further demand for research on the economic assessment of remanufacturing initiations focusing on practical implications, that is, assessment approaches that industrial practitioners easily could apply independent of their previous knowledge in economics and remanufacturing.

Here, electronic and electrical equipment products of a single OEM influenced the unit of analysis. Therefore, there is also a need for research on more types of products and companies. This would ensure that future research results are more general and applicable to a wide range of companies. Furthermore, as this research ends before the physical development and implementation of the process in practice, there is a need for longitudinal studies that encapsulate not only the exploration and assessment of remanufacturing but also the finished process. This would enable comparison and synthesis between the planned idea and the actual outcome.

Moreover, further studies on remanufacturing cooperation between a retail network and an OEM and how the relationship evolves are imperative. This research concluded that from the point of view of the OEM, it is more beneficial from a risk-management perspective to let retailers perform remanufacturing and most adjacent processes short-term and thereafter successively transition to becoming more and more separated from the retail network. Studying the evolution of the remanufacturing matureness level of OEMs and retailers, both independently and jointly, is of interest.

Lastly, further research on remanufacturing prerequisite factors to confirm the usefulness of the factors as well as to further refine and extend them is needed. Regarding the body of knowledge on how remanufacturing is initiated, there will be a need to continue to develop the factors and their categorisation.

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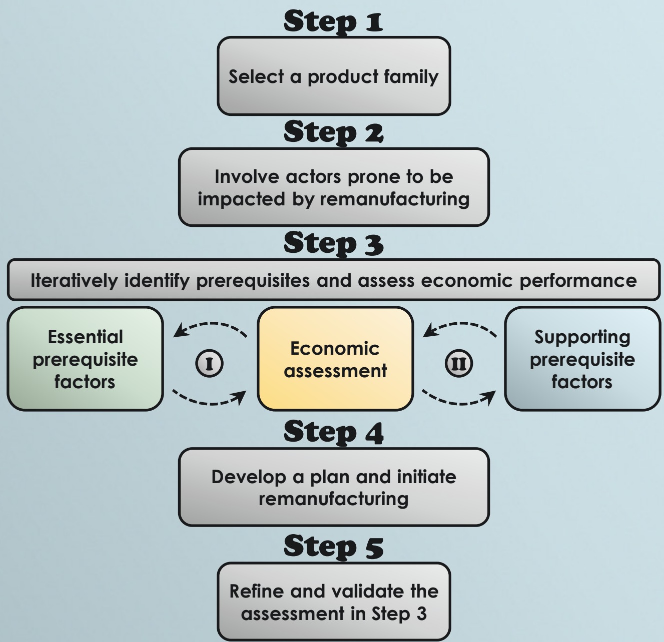

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