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From Scrap to Resources: On the Road Towards a Circular Automotive Industry

A case study at Volvo Cars regarding circular economy, value creation and value capture for End-of-Life Vehicles

Master's thesis in the Management and Economics of Innovation Program

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Department of Technology Management and Economics
Division of Entrepreneurship and Strategy

CHALMERS UNIVERSITY OF TECHNOLOGY
Gothenburg, Sweden 2020
www.chalmers.se
Report No. E2020:076

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Typeset in LaTeX
Printed by Chalmers Reproservice
Gothenburg, Sweden 2020

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Abstract

The automotive industry will face several interconnected changes in the upcoming decade, including a necessary transition to a more environmental friendly industrial climate. The industry's end-of-life (EOL) processes are identified as potentially playing a large role in improving the circular economy aspects of the automotive industry. This study hence aims to provide a deeper understanding of the current EOL process, combined with measures of how the EOL value and circularity of vehicles could be increased. The research design has been a mix of qualitative and quantitative research, with a clear emphasis on the qualitative part. Primary data has been collected through interviews and meetings with EOL-actors, circular economy experts as well as employees from the OEM Volvo Cars. These interviews have been complemented with secondary data from e.g. yearly reports, government publications and official statistics. The first major finding is the identification of the five main EOL actors: the owner, insurance company, repair shop, dismantler, and shredder. In terms of impact on value creation and circularity in the current EOL process, the dismantler and the shredder are found to be the two main actors. Furthermore, vehicles entering the EOL process are found to be subcategorised into End-of-Life Vehicle (ELV) and Pre-mature End-of-Life Vehicle (P-ELV). The ELVs are often older than 10 years and rarely have any spare part values, while the P-ELVs are othen less than 10 years old and include significant spare part values. In order to improve the values and circularity in the EOL process, three possible actions have been identified: (1) implementation of *Design-for-Disassembly* (DfD), (2) a more *structured market* for secondary parts and materials, and (3) the use of *mechanical dismantling*. Comparing the findings with theories in circular economy and value creation and capture, it could first of all be concluded that the EOL processes within the Swedish automotive industry are mainly applying circular practices such as *reuse* and *recycle*, while leaving room for a more extensive use of *remanufacture*, *repair*, and *refurbish*. Furthermore, another conclusion, and theoretical contribution, from the study is that *technological enablers* could be seen as a building block for value creation in circular economy, since technological improvements have been found to unlock both monetary values and an increased circularity. Lastly, it is also concluded that the possibilities of improving the EOL value creation and circularity is highly connected to how involved the OEM is in the EOL process, given its ability to affect and enable value added activities.

Keywords: End-of-Life Vehicles (ELV), Circular Economy, Value Creation, Value Capture, Design for Disassembly, Mechanical Dismantling, Recycling, Shredder, OEM

Acknowledgements

First of all, we would like to thank our university thesis supervisor Charlotta Kronblad, from the department of Technology Management and Economics at Chalmers University of Technology, for continuous support and guidance throughout the study. You always let us have our own take on the study, but kept us in the right direction.

We would also like to thank our company supervisor Karin André, director of Circular Economy within Global Sustainability at Volvo Cars. Your help during our weekly meetings were crucial in order to understand the problem situation, which approach we could take to solve the problems, and which people we should contact.

Furthermore, we would like to acknowledge both the circularity group and sustainability team at Volvo Cars for letting us participate during your meetings. The meetings gave us both a broader understanding of the automotive industry, overall topics within sustainability and especially the sustainability practices at Volvo Cars.

Finally, we would like to thank all the interviewees for taking their time to meet us and explain their thoughts on the subject. Among the interviewees, we would especially like to thank Magnus Wikström, CEO at Jönköpings Bildemontering, and Tom Engblom, Product Supervisor at Volvo Cars, who both gave several interviews and kept helping us over mail throughout the study. That meant a lot for our work, and we appreciate your commitment.

Erik Gedda, Fredrik Malmström, Gothenburg, May 2020

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1
Introduction

The rationale for why this topic is worth studying will be provided in the background section. This will result in a research purpose which subsequently is followed by the limitations of the study and finally the research questions.

1.1 Background

With the beginning of a new decade, the automotive original equipment manufacturers (OEMs) enters an era of uncertainty as the industry will face several interconnected changes. This includes the shift towards autonomous driving (AD) and new forms of ownership, combined with an increased environmental focus. On top of this, the more recent challenges, caused by the COVID-19 virus, makes the situation even more uncertain in terms of demand and available supply, since the pandemic has demonstrated the vulnerability associated with the current value chain structure. As a consequence, a global automotive OEM that still wishes to stay relevant in this new competitive landscape will be required to acknowledge and act upon these industry challenges (Mohir et al., 2016). Within the scope of the environmental challenges, much of the focus has been towards the electrification of vehicles and actions aimed to reduce emissions, which have had a significant effect on an individual vehicle level. Although, as car ownership continues to increase at a global scale, an important aspect in the strive for aggregated emission reduction is to increase the automotive industry's circularity, including new processes regarding end-of-life vehicles (ELVs). According to Ellen MacArthur Foundation (2019), circular economy has the potential to reduce the global CO2 emissions from steel, plastics, cement, and aluminium by 40% in 2050. Today, the production of these four materials stand for approximately 6,7 billion tonnes CO2 on yearly basis (Ellen MacArthur Foundation, 2019). Given that passenger cars and buildings account for approximately 73% of the emissions from producing these materials (Material Economics, 2019), it is evident that the industries will need to transform in order for the world to achieve a more sustainable future.

Similar to several other manufactured products, an automotive traditionally undertakes three main stages throughout its life cycle. This includes the beginning of life (BOL), where the main activities includes manufacturing and product design, followed by middle of life (MOL), focusing on tasks such as logistics, repair and maintenance. The third and final step includes a products end of life (EOL) where a range of activities are possible (Spielmann and Althaus, 2007). A product can be reused, repaired, refurbish or remanufactured, allowing it to experience a secondary life, as well as being recycled, recovered and/or disposed (Kiritsis, Nguyen, and Stark, 2008). According to directives from the European Union, at least 85% of a passenger car has to be recycled and at least 95% should be recycled or recovered during the EOL stage (Directive 2000/53/EC, 2000). Amongst the former percentages, parts or material should be handled according to some of the mentioned second life alternatives or being recycled, which certainly is allowed to surpass 85% if possible. The remaining leftovers from the shredding process, often referred to as fluff (House, 1995), are allowed to be recovered, e.g. by incineration, up to 10% of the original mass whilst the remaining material will end up at landfills (Jensen et al., 2012). The OEM within the car industry is responsible to provide the opportunity for this EOL process to happen in a way that complies with the EU directives (Directive 2000/53/EC, 2000). This is usually done by an extensive network of enterprises and stakeholders that operates independently or in cooperation with the OEMs (Sakai et al., 2014).

In order to fully grasp the properties of an automotive's EOL, it may require a deeper understanding of what the different stage activities imply. Considering remanufacturing, it generally refers to a process in which a used product undergoes various treatments in order to obtain a capacity that is equivalent or better to the same product in its virgin stage (Garetti and Taisch, 2012; Matsumoto et al., 2016). Regarding a refurbished product, it as well undergoes some treatment with the objective of an increase in capacity. The distinction between a refurbished and a remanufactured product is that the former only requires to fulfill a pre-specified level of performance, which by definition is lower than that of the virgin product (Jayaraman, 2006). Moreover, Jayaraman (2006) describes the properties of a reused product as having sufficient enough capacity left that it is able to still manage quality standards without adding any additional resources. To repair a product implies the restoring of something that is broken to its previous quality. Combining the mentioned activities with the general properties of recycling together enables a resource management view that is of a cradle-to-cradle character, rather than cradle-to-grave which is generally the case with disposed landfill material (Kumar and Putnam, 2008).

This thesis investigates the EOL process for automotives from the perspective of Volvo Cars, a Swedish OEM. Volvo Cars has decided to act upon several of the industry challenges, including conducting and advertise ambitious targets regarding CO2 emissions and circularity until the year of 2040. Although currently managing to cope with the EU directives, the company has decided to go public with even more detailed ambitions regarding the circularity of their business model. Some of the first milestones for the 2040 vision are that by 2025 having at least 25% recycled plastic and steel together with 40% recycled aluminium in their cars as well as cutting down on company wide CO2 emission with at least 40% per vehicle (Volvo Cars, 2019). Volvo Cars emphasise the importance of managing the EOL process for their vehicles in order to accomplish these ambitious goals. Although this being the case, the company claims to have a lack of knowledge about the actual and potential value of an ELV, and suspect that it might have different values depending on who the value concerns. For example, it might have one value as material recycled at a recycling station, but another value if the components and materials would be remanufactured, reused or recycled into the car manufacturer's own production. Given that the amount of waste that yearly can be derived to ELVs is exceeding 8 million tonnes on a yearly basis (Aigner et al., 2020), it is likely that the internal consensus at Volvo Cars is correct regarding the potential of increasing its EOL efficiency, both at a company as well as a market level.

1.2 Purpose

This study explores the EOL processes for automotives from a Swedish perspective, and connects these processes to theories within circular economy as well as value creation and value capture. The goal is to provide a deeper understanding of the current EOL process, combined with measures of how the EOL value and circularity of vehicles could be increased. Furthermore, an investigation is made into the potential role of an OEM into this process and how that may impact the value and circularity of the ELVs.

1.3 Limitations

The study is geographically limited to primarily include data from Swedish and secondarily European EOL stakeholders. It cannot be excluded that the potential values would be different in other parts of the world but given the study's resource limitations, it would be hard to manage a worldwide analysis.

Furthermore, the study is limited to only investigate the potential EOL value that could be derived from different second life recycling alternatives. Thereby the study excludes other potential EOL values, for example researching if prolonging or shortening the life-time of a car could somehow optimise the value. The rationale behind this is that a car that has the possibility to have a prolonged life is by definition not at the end of its life. Hence, when referring to EOL material, it will be the material and the parts that can be derived from the vehicles. The discussion surrounding value creation and capture will hence be considered from the perspective of EOL materials and parts.

In addition, when analysing the current and potential values in the EOL process, this study focuses on monetary values such as income and profitability. Other values that could be generated from the EOL process, such as e.g. brand values and strategic values, are hence not included in this study. Within monetary values, the main focus lies on income and primarily the question of how much income that could be generated from a vehicle entering the EOL process. The rationale for not focusing on profits as much as on income is that profit depends on both income and cost, and it would be too time and resource consuming to analyse both. The costs connected to vehicles in the EOL process seem more difficult to analyse than the income, since the costs often are distributed over different products, facilities and tasks.

Volvo Car Group consists of six subsidiaries (see Section 2.1). This study is focused only on the fully owned subsidiary with vehicle production, i.e. Volvo Cars. The two fully owned subsidiaries Care By Volvo and M are subscription and car sharing based business models respectively, and do not produce any cars on their own. Instead, they are based on the cars produced by Volvo Cars. Hence, from an EOL perspective, the most relevant subsidiary is Volvo Cars given that it constitutes the vehicle supply for all these three actors.

Moreover, the study leverages internal secondary sources (see Section 2.3.2) of Volvo Car Group. Although the final output is a combined product between the authors and the company, sources provided by VCG with the objective to provide a deeper understanding for the topic at hand and potential solutions but simultaneously contains company sensitive information, are not included in the report. The rational behind such a limitation is that it may contain company sensitive information that have been provided during the premises of a None-Disclosure-Agreement and can hence not be published.

Finally, the study was performed during the pandemic eruption of COVID-19 throughout the world, which caused severe societal consequences. This increased the need for social distancing in order to hamper the infection rate, which made it considerably more difficult to contact potential interviewees. Moreover, the economic consequences of COVID-19, including layoffs and furloughs, caused a limitation of the time available for both internal Volvo employees as well as external primary sources to participate in interviews.

1.4 Research Question

In order to achieve the purpose of this thesis, the following four research questions have been stipulated,

RQ1: What does the current end-of-life process look like given the inter-relationships between all its identified stakeholders?

RQ2: What monetary value is created and captured during the current end-of-life process with respect to each stakeholder?

RQ3: In what way could the value for the end-of-life process increase? What are the barriers for doing so and what could be the role of an OEM in this process?

RQ4: What are the circularity impacts that the current process gives rise to and how are these affected by the identified value added activities?

2 Methods

The following section will introduce the methodology used throughout the study. The rationale behind each decision will be explained, based on references to theory.

Edmondson and McManus (2007) suggests that management research theories fall on a continuum from nascent, to mature. Nascent theories propose answers to novel questions in previously not well-researched areas. Mature theories on the other hand, are often well-developed models and theories in areas that has been studied thoroughly over long time. Positioned in between nascent and mature theories, Edmondson and McManus (2007) place intermediate theories, and describe them as theories that often combine established constructs with new research in novel areas. As described in the introduction, this study aims to investigate the current state of the EOL process for vehicles, including monetary value in terms of income, together with how the EOL process can be redefined in order to unlock a higher value and increase the circularity. Moreover, the study will investigate what the role of an OEM, with a particular focus at Volvo Cars, can have in order to increase these values. This aim will require theories in the areas of both value creation and value capture as well as circular economy, including what challenges and barriers there are in engaging in the EOL process. Value creation, value capture and circular economy are areas with a lot of existing research. However, there is not much existing research on the combination of the topics, especially in a specific setting as the automotive industry. Based on this, it could be argued that the potential theoretical contributions from this study would be positioned somewhere between nascent and intermediate along the continuum described by Edmondson and McManus (2007).

2.1 Research Strategy

Edmondson and McManus (2007) states that when management theories are nascent, a qualitative research approach is suitable, and when the theories are mature, a more quantitative approach is suitable. When the theories ends up in between nascent and mature, as intermediate theories, a hybrid approach is suggested by the authors. Given that this study could be considered somewhere between nascent and intermediate, and interviews with stakeholders and external experts have been the main sources of data, the study heavily emphasised on the qualitative aspects.

Considering that the aim of a study was to understand and assess the critical issues of a problematic situation, instead of giving a definite answer, an exploratory research design is suitable (Sreejesh, Mohapatra, and Anusree, 2014). Sreejesh, Mohapatra, and Anusree (2014) further states that one can use an exploratory research because of three main reasons, namely (1) to analyse a problem situation, (2) to understand and evaluate alternatives and (3) to come up with new ideas. Given that the aim of this study was to understand the EOL process, and to come up with and evaluate new possible EOL processes, including the OEM's perspective, an exploratory research design was deemed suitable and has also been applied. Moreover, given that the observations were gathered before concluding the analogy to theory, the study applied an iterative approach in order to accomplish a fully transparent picture. Furthermore, the chosen strategy for this report was a case study. The rational behind this was that the working process aimed to resolve a practical problem for the organisation at hand, i.e. how Volvo Cars could aid in the EOL process and leverage it to become more circular. Moreover, according to Denscombe (2018), a case study is a reasonable choice of strategy when one wishes to grasp the compounded relationships between internal and external stakeholders and their part in the process. Also, according to Bryman and Bell (2007), a case study approach is feasible for an exploratory research strategy, which further strengthens the rational for the selected strategy.

2.2 Research Setting

Below follows a description of the main features that in combination build up the framework from which within this study was conducted.

2.2.1 Company Characteristics

The following section mainly builds upon public information provided in Volvo Car Group Yearly Report (2019) and www.group.volvocars.com. For reader simplicity, references will only be made towards sources that does not include the mentioned.

The first Volvo car was created 1927, at a time when Volvo Cars only was referred to as Volvo. This in turn was a wholly owned subsidiary of the Swedish ball-bearing manufacturer SKF. During its history, the car manufacturing branch of Volvo has been a major business unit and it has coexisted with the manufacturing of products like trucks, busses heavy equipment vehicles (HEV) and boat engines. This remained up until the year of 1999 when the automotive part of Volvo Group was broken free and sold to the Ford Motor Company. Volvo Cars remained during the ownership of Ford until 2010 when Volvo Cars was sold off to the parent company of the Chinese car manufacturer Geely Automotive, Zhejiang Geely Holding Group. From here, the creation of Volvo Car Group (VCG) has emerged, which subsidiaries are to be found in Table 2.1. Today, Volvo Cars is a global car manufacturer with over 40 thousand employees and 700 thousand cars sold during the previous year of 2019. The company has manufacturing in Europe, Asia and America, and the cars are sold at all continents. From a Volvo Cars perspective, the company offers three major types of automotives. It is the S-models, including sedans, the V-models, including wagons and the XC-models, including SUVs. Moreover, all the mentioned models offers several size alternatives. Table 2.2 illustrates the amount of Volvo Cars total sold during 2018, allocated towards each offered car model.

Table 2.1: Volvo Car Group Subsidiaries

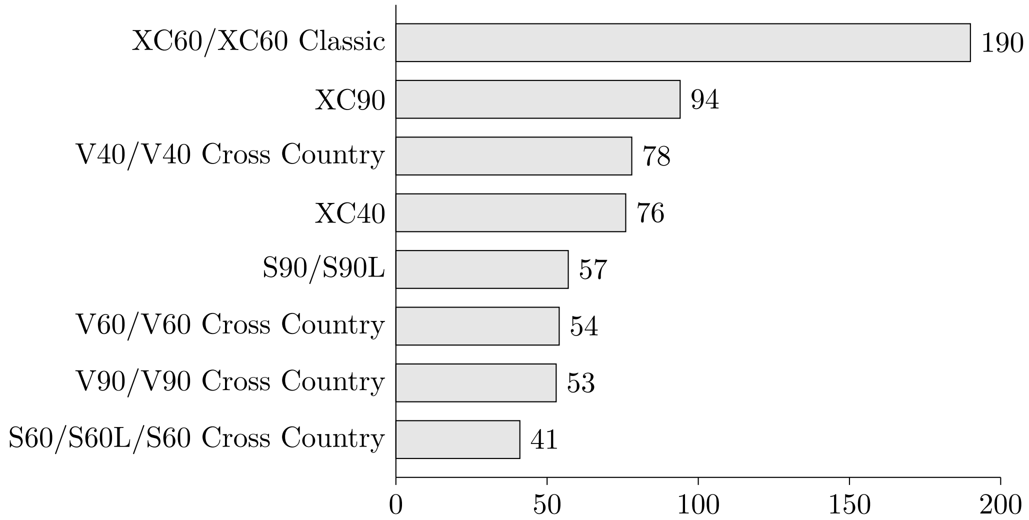
Company	**Description**	**Ownership**
Volvo Cars	*Designs, develops, manufactures and sells premium cars. VCG's oldest and main business area*	100%
Care by Volvo	*A subscription based car ownership aimed to increase customer relationship and supply chain control - My Car Always -*	100%
M	*A global mobility operator that applies a shared subscription based ownership in urban environments - My Car Sometimes -*	100%
Polestar	*A wholly electric car manufacturer that targets an even higher premium segment, with an increased focus on China*	50%
Lynk & Co	*A car manufacturer that implements a modern shared and flexible ownership. Currently only active at the Chinese market*	30%
Zenuity	*Focus on software development, including sensing and vehicle control, for autonomous driving, used internally as well as externally*	50%

Volvo Cars has established car production in four countries: Sweden, Belgium, China, and the US. During 2018, 44% of all cars were produced in the Swedish factory, which is situated in Gothenburg. The remaining car units were dispersed accordingly: 30% in Ghent, Belgium, 25% in Chengdu, Daqing and Luqiao, China, and 1% in the Charleston, US where the plant was established as recently as in June that year. Furthermore, Volvo Cars also operates two assembly plants in Kuala Lumpur, Malaysia and Bangalore, India. Volvo Cars largest markets are Europe, China, and the US. In terms of retail sales, these three markets represented 50%, 20% and 15% respectively during 2018. Within Europe, Sweden is the largest market, followed by United Kingdom, Germany, and Belgium. In total, Volvo Cars sold over 640 thousand cars during 2018, something that increased to over 700 thousand cars during 2019.

2.2.2 ELV Directives

Throughout the European Union, ELVs are yearly responsible for 8 - 9 million tonnes of waste. In order to align the efforts from all member states in terms of coping with this mountain of waste, together with ensuring a safe and environmental friendly EOL treatment, the EU drafted the Directive 2000/53/EC (2000), advocating a

Table 2.2: Overview of retail sales by carline (thousand units) for Volvo Cars 2018



coherent ELV treatment amongst its member states. The directive stipulates that a preference when handling ELV materials should be given to reuse and recycling before considering recovering and thereby aims to minimize the amount of landfill material per vehicle. In measurable terms, the directive stated that by 2006, reuse, recycle and recovery should be at least 85% of a vehicles weight. By 2015, this percentage was increased to 95%, with 85% being reuse or recycle. Hence, energy recovery could span from 10 to 15% and 5% is the maximum percentage of acceptable landfill usage. Moreover, the directive emphasises that all OEMs should ensure that these levels of reuse, recycle and recovery are reached by a producer responsibility. The most dominant way of doing so is through partnerships with EOL stakeholders. Furthermore, the directive also states that an OEM should, after the best of its abilities, design vehicles in order to facilitate the EOL treatment as well as encourage markets for ELV material.

2.3 Data Collection

Much of the data collection occurred through interviews where the outcome were of a more qualitative character. This was then further complemented with documents in order to provide a deeper knowledge, benchmark values, increase the level of validity and enable conclusions. Hence, the thesis leveraged a mixture of both primary and secondary data sources.

2.3.1 Primary Data Sources

As mentioned earlier, an exploratory approach was applied in order to investigate into the purpose of this study. To gather the data needed for understanding the problem, interviews with employees, stakeholders and different experts were conducted. According to Denscombe (2018), conducting interviews is an appropriate research method when the aim is to understand complex issues, including how things work, how different factors are connected or how systems operate. Given the open-ended character of the latter research questions, these statements appeared very much aligned with the purpose and hence, the study emphasised heavily on interviews throughout the working process. The interviewees constituted of a mix between internal OEM stakeholders, which all had a Volvo Cars connection throughout the study, and external stakeholders, including both experts and EOL actors. In total, 21 interviews were conducted with a total of 20 different interviewees (see Table 2.3). Throughout the interviews, a general approach was to allow participants to shed light on general possibilities and barriers of circular economy in the automotive industry as well as there view of value creation and capture. By leveraging a semi-structured format, interviewees were allowed to speak more freely, something that before hand was found suggested by Denscombe (2018). Moreover, in order to build a deeper understanding of the ongoing sustainability discussion within the automotive industry, several internal meetings were attended, combined with supervision sessions (see Table 2.4). Although not a major direct contributor to the study findings, these meetings have provided information at a higher level which then have been leveraged when analysing the more measurable findings.

2.3.2 Secondary Data Sources

As a complement to the interviews, different secondary data sources have been leveraged in order to get a more holistic view of the topic, but also to find specific data measurements needed to answer the research questions. According to Sreejesh, Mohapatra, and Anusree (2014), theory sources can be considered as either of internal or external character. The internal sources refers to information available within the organisation itself, in the case of this study it implies Volvo Car Group. This have included public available production, financial and marketing numbers. The external sources that have been used throughout the study includes government publications, yearly reports and official statistics regarding the automotive industry, as well as books, articles, and company reports. Official statistics and government publications tend to have credibility, be regarded as impartial, and constitute “hard facts” (Denscombe, 2018; Sreejesh, Mohapatra, and Anusree, 2014). The study have advocated an approach where several different data sources were being considered in order to provide a sufficient enough number of benchmarks to the findings from the primary sources. When addressing the quantitative aspects of the research questions, the secondary sources were used to such an extent that the researcher felt comfortable with the obtained amount of data collected. In cases where the primary data sources could not provide any indication of, e.g. measurements or process activities, the secondary data sources have been accepted at face value.

2.4 Research Findings and Analysis

Given the iterative aspect of the selected research strategy, together with the interconnections between the stated research questions, this study has conducted its analysis in parallel with the findings. As stated, much of the data sources will be of a qualitative sort and therefore it was considered useful to perform the findings

Table 2.3: Overview of the study interviewees

Interviewee	Type	Role	Date
Bernard Uittenhout	Int	ELV Manager	2020-01-24
Tom Engblom	Int	Product Supervisor	2020-01-29 2020-02-03
Henrik Nordell	Int	Sr Spec. Resource & Waste Mgmt.	2020-02-03
Jenny Strömberg	Int	Product Innovation Manager	2020-02-03
Sandra Tostar	Int	Tech. Specialist Polymer	2020-02-10
Magnus Wikström	Ext	CEO – JB	2020-02-11 2020-03-31
Tina Carvid	Int	Senior Project Manager	2020-02-13
Matilda Green	Int	Product Business Manager	2020-02-13
Jonas Otterheim	Int	Head of Climate Action	2020-02-14
Einar Kjartansson	Ext	Head of Motorteknik - LF	2020-02-17
Flemming Jensen	Int	Macro Specialist	2020-03-02
Marcus Linder	Ext	Sustainable Bus. Director - RISE	2020-03-03
Anders Sverkman & Sverker Rosdal	Ext	Stena Recycling	2020-03-04
Thomas Almen	Int	Director	2020-03-05
Robert Westerdahl	Ext	Partner - Material Economics	2020-03-05
Hanna Ljungqvist Nordin	Ext	Sustainable Consumption - IVL	2020-03-16
Dag Eklund	Ext	CEO - Eklunds	2020-03-18
Andreas Andersson	Int	Env. Attribute & Material Mgmt.	2020-03-23
Sven Bäckström	Ext	CEO - JBF	2020-04-03

and analysis activities simultaneously. It is often the case that ongoing findings, and its subsequent analysis, affects the data which later will be collected. This since it provide guidelines for what is relevant to investigate, and hence not overwhelming the researcher (Suter, 2006). Moreover, it would had been cumbersome to collect data regarding th e later research questions without investigating into the properties of the earlier. According to Harding and Whitehead (2013), data analysis during qualitative research can be performed in three main ways. The most traditional way is to gather all the data, and thereafter analyse, similar to exclusively quantitative research and hence not suitable in this study. Another alternative is to perform the analysis after each type of data, e.g. interviews or forms, which also was deemed

Table 2.4: Overview of internal meeting participation

Name	**Description**	**Occurrences**
Supervision	*Regular meetings with supervisor Karin André, Director of Circular Economy at Volvo Cars, regarding the work progress*	21
Sustainability Stand-up	*Department meetings for the sustainability group at Volvo Cars regarding the daily operations*	11
CE Group	*Meetings with a cross functional working group regarding Circular Economy efforts at Volvo Cars*	3

cumbersome given that each data source provided guiding for new sources. This study therefore applied a constant comparative analysis with constant analysis of the findings (Harding and Whitehead, 2013). For an overview of only the findings, excluding its subsequent analysis, see Appendix A.

2.5 Research Estimations

In order to achieve viable numerical results within the scope of the stated research questions, the study has emphasised the usage of estimation findings, based upon several identified historical data measurements. Given that a sparsely amount of estimation methods for size and income were found, the thesis has instead investigated and leveraged the knowledge of scholars within the cost-based estimation techniques expertise. An important aspect to consider in order to achieve validity for these estimations, is to ensure that the historical data is representative for the current and future state (Mislick and Nussbaum, 2015). According to Bil Sweden (2019), the Swedish automotive industry is in a mature stage of its development, with a fairly modest growth in terms of yearly registered vehicles. The same can be argued for the amount of de-registered vehicles, although this segment is experience a delay towards the newly registered vehicles, given the average usage time of a car. However, given these characteristics of a mature market, this indicates that the identified measurements can be leveraged within the estimations analysis. Moreover, before each estimation based finding in chapter 4, an initial overview of the identified measurements is provided as well as the applied estimation technique, in order to achieve both a sufficient transparency level as well as replicability (Mislick and Nussbaum, 2015).

The study has applied three types of estimate approaches when quantifying aspects such as size or income, namely the (1) *top-down*, (2) *bottom-up* and (3) *ethereal* approaches. Considering the top-down approach, it has been applied in situations where the overall number is known but the specific measurements are of a less specific character, and hence not possible to draw a comprehensive conclusion from. The known “top number” has therefore been leveraged as foundation for the estimation, in order to include unforeseen risks and aspects (Association for Project Management, 2019). Given that the outcome of a top-down approach usually is considered as a ballpark estimate, the final outcomes connected to this technique have been illustrated by more even numbers throughout the report. Furthermore, bottom-up estimates have been used where the found measurements provided a sufficiently detailed foundation in order to conduct a comprehensive final number. The technique has a better ability than the top-down approach to estimate more detailed and low level activities (Association for Project Management, 2019) and has hence been used accordingly. The final approach, ethereal estimation, is based upon estimations of external sources that have to be considered at their face value, and hence provides a significant degree of uncertainty given the hardship of validation (Association for Project Management, 2019). It has although been applied in combination with the two other techniques, in situations where some measurements only could be gathered through specific expertise knowledge or required a too extensive research work as in comparison to this study's resources, in order to achieve own estimations.

2.6 Ethics

According to Dienrer and Crandall (1978), ethical areas to consider when conducting research in a business context involves *harm to participants*, *lack of informed consent*, *invasion of privacy* and *involvement of deception*. Bryman and Bell (2007) amplifies to this list by considering ethical issues related to *data protection*, *conflict of interest* and *trust*. Together, these parameters provides the foundations on to which one conducting this research should consider the ethical aspects.

In this type of research, it is likely that one will be provided with information that to some degree is sensitive. This study has been no exception to this and all information that have been indicated by its original source as sensitive and/or secrete has been handled accordingly. By handling the information with respect, the study hopes to ensure its participants that no harm will occur to him or her personally. The interview questions have been formulated in such a manner that they did not invade on the interviewee's privacy nor being deceiving, in accordance with the suggestions from Dienrer and Crandall (1978). Moreover, it was evident beforehand that some conflict of interest may occur amongst stakeholders towards the OEM in question. More precisely, partner companies would probably be keen on having a good relationship with the OEM whilst simultaneously not compromising their own business by disclosing too much information. Hence, the data provided by all stakeholders have been handled in a way that is trustworthy and causes no harm, whilst simultaneously contributes to the research purpose.

3

Theory

The following section will introduce the theoretical aspects that are deemed relevant for conducting a discussion within the thesis scope. The main focus will be towards circular economy, value creation and value capture.

3.1 Circular Economy

In a traditional producing industry, actors generally operates according to the take-make-dispose paradigm. Business models have been refined in a strive for excellence but merely from a cradle-to-grave perspective (Hopkinson, De Angelis, and Zils, 2020). As the environmental aspects have reached higher upon peoples' and societies' agendas, it could be argued that a paradigm shift is currently occurring within the traditional product life cycle knowledge. It has been proven that factors such as cradle-to-cradle and regenerative design could increase eco-efficiency as well as lowering life cycle emissions and hence the circular movement has also gained momentum over the recent years (Braungart, McDonough, and Bollinger, 2007; Lyle, 1994). Except from the evident fact of how an increased degree of circularity can contribute to a more sustainable future, there exist substantial economical values to be captured in the transition to a more circular economy. Lacy, Long, and Spindler (2020) estimates an upside of 4.5 trillion USD, and hence what at first may seem like challenges may in fact be tremendous opportunities.

Whilst browsing through the vast amount of articles, books and reports written by circular economy scholars, it is cumbersome to find an universal definition of the concept. Given that the topic has contracted momentum, so has subsequently different definitions emerged from what could be considered as a fairly straight forward concept. Kirchherr, Reike, and Hekkert (2017) systematically analysed 114 different definitions in order to investigate the most prominent features of the research community's perception about the topic, resulting in the following definition of a circular economy,

> "An economic system that replaces the 'end-of-life' concept with reducing, alternatively reusing, recycling and recovering materials in production/distribution and consumption processes. It operates at the micro level (products, companies, consumers), meso level (eco-industrial parks) and macro level (city, region, nation and beyond), with the aim to ac-

> complish sustainable development, thus simultaneously creating environmental quality, economic prosperity and social equity, to the benefit of current and future generations. It is enabled by novel business models and responsible consumers (Kirchherr, Reike, and Hekkert, 2017)".

Moreover, Ellen MacArthur Foundation (2019) states that in order to manage the transition to circular economy, it is vital to (1) Design out waste and pollution, (2) keep products and materials in use, and (3) regenerate natural systems. Furthermore, a distinction can be made between the concepts of biological and technical circularity. The biological cycles concern biologically based materials, and processes like composting and anaerobic digestion whilst technical cycles concern the recovery and restoration of products, components, and materials through reusing, repairing, remanufacturing, or recycling (Ellen MacArthur Foundation, 2019). Given the configuration of the producing industry, a natural emphasis for the thesis at hand will be towards the technical cycles and to what extent a circular approach can reduce the need for virgin resources as well as landfills (Wells and Seitz, 2005).

3.1.1 Degrees of Circularity

Circular economy is highly interconnected to the concept of closed loop, often in combination with words like systems, manufacturing or production. Although being a vital concept, circular economy scholars claims that only referring to closed loops is somewhat deceptive and eviscerated. Bockena et al. (2016) advocates that the loop concept of circular economy can be subcategorized into three type of loops, namely (1) a *slowed* loop, (2) a *narrowed* loop and (3) a *closed* loop. The former refers to prolonging the resource life, which in turn is enabled through actions such as remanufacturing and repair. If managed successfully, the initial virgin material will suffice over a longer time period and hence increase its utilisation. The concept of a narrowed loop implies providing similar output but with less input. It is in many way an efficiency measure that always has existed to some extent, given its evident result in terms of profitability. The third and final loop type refers to connecting the post-use step with production and thereby achieving a fully recycled and closed flow of material (Bockena et al., 2016). In addition, Geissdoerfer et al. (2018) adds the concept of an *intensified* loop, emphasising the importance of a more intense use phase. Stahel (1994) also advocates the need for distinguishing between loop types, although considers it sufficient with two type of loops, namely (1) the reuse of goods, implying an extension of its utilization grade, and (2) the recycling of materials to its original state or downcycled, in the case of its recycled capabilities are not able to match those of its virgin equivalents (Wells and Seitz, 2005). Moreover, Wells and Seitz (2005) argues that a closed loop may occur at four different stages within the product life cycle, as explained in Table 3.1.

3.1.2 Second Life Hierarchy

A central concept within circular economy is to enable for products and materials to experience a second life. Carelessly speaking, it is argued that the strive should

Table 3.1: Different type of closed loops (Wells and Seitz, 2005)

Loop Type	**Description**
Internal	The usage of waste in production to reproduce materials. Could arguably be considered as an efficiency measure.
Post-business	Materials are recovered and recycled between different supply chain actors.
Post-consumer	Refers to a reversed flow from the EOL back into the early industry supply chain activities.
Post-society	Materials are recycled in the sense that the society can benefit upon it in other sectors.

be towards the recycling of products, when in fact the second life hierarchy is far more complex than this. Factors such as the amount of labour and energy that is needed in order to provide a second life for products determines how much there is to gain from an environmental and a business standpoint, compared to the usage of virgin products and materials (Korhonen, Honkasalo, and Seppälä, 2018; Mihelcic et al., 2003). Gharfalkar, Zulfigur, and Hillier (2016) advocate that from a circular perspective, the most resource efficient alternative is to reuse the products, since this alternative barely requires any additional features. Subsequently follows repair, refurbish and remanufacturing (see section 1.1 for explanation) and lastly recycling. To recycle a product in this more transparent manner often requires a substantial amount of resources whilst simultaneously may downgrade the material, implying the creation of a less efficient material and in a sense only prolonging the linear flow (McDonough and Braungart, 2002), i.e. slowing the loop. Material can also be recovered through actions such as incineration, enabling an increase in its utilization but also exiting the material from a circular flow. Moreover, to dispose the material at landfill marks the end of the circular flow of the product (Gharfalkar, Zulfigur, and Hillier, 2016).

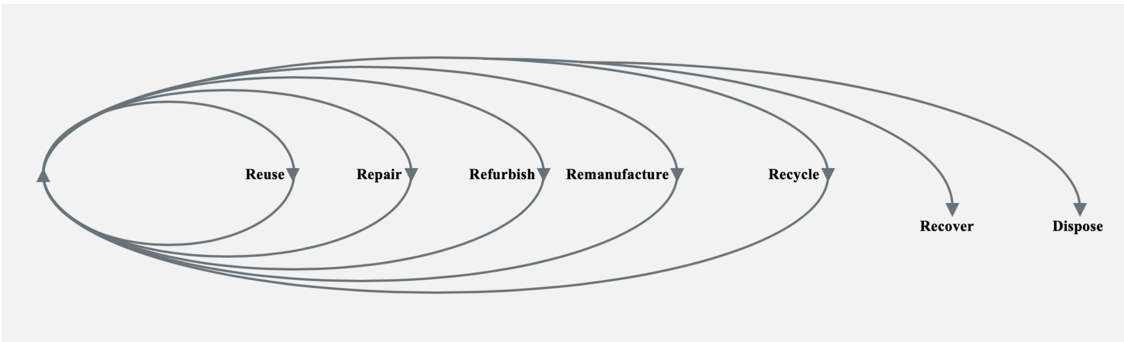


Figure 3.1: Hierarchy of second life alternatives

3.1.3 Barriers and Enablers for Circularity

Although having an overall quantifiable value that stipulates the potential for a business society to turn circular, it may be less evident for each individual actor regarding the business rational of turning circular. Houston et al. (2020) has investigated into which barriers and enablers that European businesses experience in the quest for a circular economy. Considering in-house barriers, i.e. barriers that appears within the company, it was found that the lack of clear consumer demand for circularity, resistance to make changes in the business model and the associated upfront costs of new investment composed obstacles for a more circular approach. If broadening the spectra and including the entire value chain, the lack of secondary markets as well as the current logistic network together with the prevailing principles of design thinking excessively hampered the circular development (Houston et al., 2020). In the context of enablers, it was found that major in-house factors were high-level commitment with long term perspective, an overall positive attitude and a clear vision of potential value creation. For the value chain as a whole, stakeholder collaboration, an increased degree of standardization and internal to regional circular action spillovers were identified as key aspects to enable the circularity transition (Houston et al., 2020). It could further be argued that factors such as technological lock-in, lack of capital, the need for scale and none-desirable legal aspects provides a challenge for the strive to circularity (Rizos et al., 2016).

3.2 Value Creation and Capture

To analyse where in the EOL process value is created and captured, this paper is using thoughts from Bowman and Ambrosini (2000). In their paper, they discuss what value is, valuable resources are, how value is created, and who captures it.

3.2.1 How Value is Created

A distinction can be made between *use value*, which is the customer's subjective perception of the usefulness of the product or resource, and *exchange value*, which is realised only at the time when the sale takes place (Bowman and Ambrosini, 2000). The authors further states that total monetary value is the amount that the customer is prepared to pay, and therefore dependent on the perceived use value. Use value can be created by labour and actions from organisations in the value chain. However, how much exchange value this increased use value has added can only be determined when the created use value is sold (Bowman and Ambrosini, 2000). The nature in which value is created may differentiate depending upon industry structure. Value can be derived from joint activities between stakeholders, and the relationship itself is therefore an enabler for unlocking the potential. On the contrary, there exist intrinsic values, implying that each stakeholders capabilities create value but that this is independent of collaborative activities between each other (Tescari and Brito, 2016). In a relationship setting, Lindgreen et al. (2012) argues that values appear more easily when the exchange become predictable combined with an increased understanding and adoption of the involved parties.

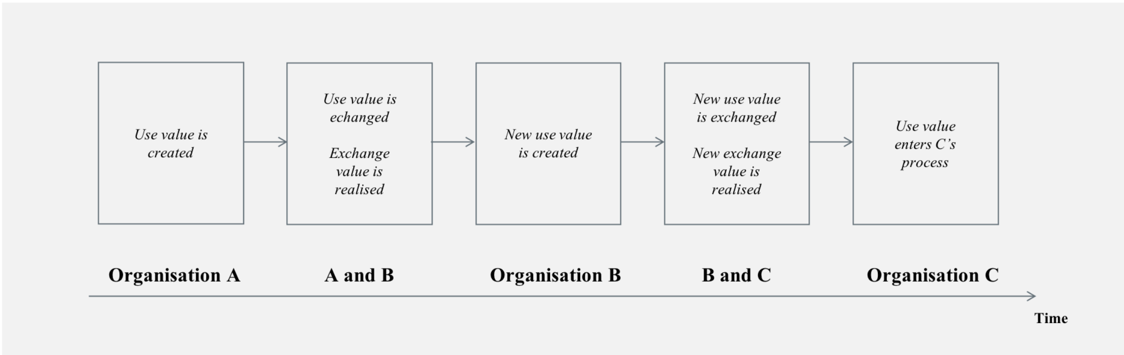


Figure 3.2: The value creation process

3.2.2 How Value is Captured

How much the firm that is creating the use value actually can add to their exchange value when selling the product, i.e. how much of the created value they can capture, depends both on their suppliers and their customers, and their perceived power relationship (Bowman and Ambrosini, 2000). Although the source of the use value creation comes from actions within the firm, the amount of profit realized on exchange of those products is determined by (1) the customers' comparison between the product, their needs, and other companies' products, as well as (2) the resource suppliers' comparison between their deal with this firm, and potential deals with other buyers (Bowman and Ambrosini, 2000; Lindgreen et al., 2012). In other words, the value captured is determined by the bargaining power relationship between buyers and sellers (Bowman and Ambrosini, 2000). Moreover, factors like substitution and switching costs, similar to the forces described by Porter (2008), can according to Bowman and Ambrosini (2000) also affect the ability to capture value. How much of the exchange captured value from the customer that goes to the firm or its resource suppliers depends on the bargaining relationship between them. If a supplier is in a powerful position, it has the opportunity to capture a larger part of the exchange value won from the firm's customers. If the supplier has a weaker position, it will capture less of the exchange value.

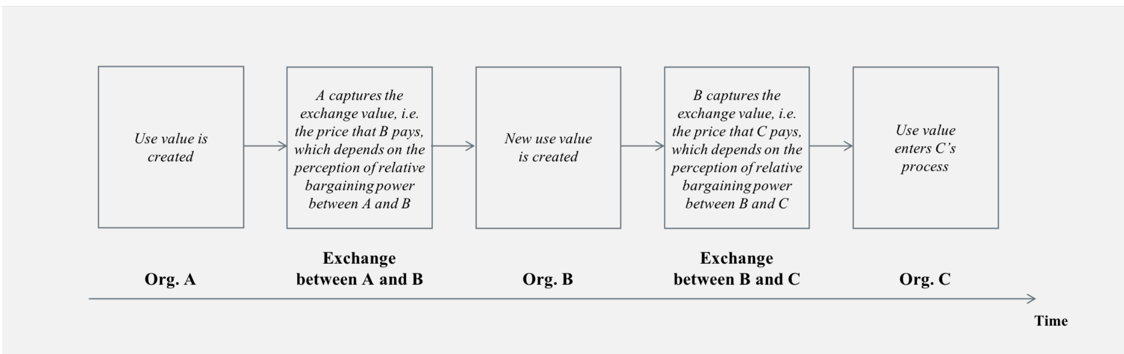


Figure 3.3: The process of value creation and capture

3.3 Value Creation in Circular Economy

Hopkinson, De Angelis, and Zils (2020) present four key building blocks that could be used to frame circular value creation, including (1) *circular design*, (2) *new business models*, (3) *reverse network management* and (4) *system enablers*. Furthermore, Hopkinson, De Angelis, and Zils (2020) advocates that material flows in circular economy can be categorised in technical and biological cycles, where technical cycles are the material flows of synthetic materials while biological cycles concern renewable materials. Since this paper is scoped within the automotive industry, technical cycles are the more relevant of the two. Hence, this section will present the four building blocks from the perspective of technical cycles.

3.3.1 Circular Design

In technical cycles, value can be realised through different EOL strategies, such as maintenance, remanufacturing, and recycling (Hopkinson, De Angelis, and Zils, 2020). The product design plays an important role in terms of its ability to recover and recapture value from the EOL stage, to enable efficient and effective material flows (Hopkinson, De Angelis, and Zils, 2020). Regarding product design, several alternatives exist that would have the potential of increasing the circularity. In broad terms, one should aim for an increase in standardisation of components, purer material flows, and create a more eco-efficient design (Ellen MacArthur Foundation, 2013). More particular, this include design for durability, repairability, disassembly or recycling as well as extending use or enabling upgradeability through modularity (Lacy, Long, and Spindler, 2020), to mention a few examples.

3.3.2 New Business Models

Business models sets the scene from which a company is conducting its core activities and once this state is established, it is in general difficult to allocate investments onto ad-hoc projects that does not clearly align with the overall strategy (Magretta, 2002; Teece, 2010). Moreover, in an era of industry innovation, a dominant and previously viable business model can cause firms to miss out on potential new business opportunities or not managing to cope with industry disruption (Chesbrough, 2010). Hopkinson, De Angelis, and Zils (2020) present the three types of circular business models they consider to be the most common and successful ones: resale/re-commerce, performance-based models, and internalisation. Resale models reintroduces products into a market, performance-based models are often different types of pay-per-use deals, and when companies use circular practices in e.g. their upstream operations or production processes, to become more cost competitive, it is called internalisation (Hopkinson, De Angelis, and Zils, 2020). Since the internalisation and resale/re-commerce business models are the ones most connected to the EOL processes, this thesis focuses mainly on different types of business models within those areas. Below follows a more thorough description of different business model alternatives.

Extending product value - A method where a downstream actor from the customer's point of view aims to leverage on the residual value in order to further create business opportunities. It involves to recover parts or products that is no longer desirable in the market context and to handle these in such a way that it extends the life time for which value can be provided (Bockena et al., 2016). It is common that the original producer disregards this business opportunity and that it instead is exploited by external actors, i.e. gap exploiters (Bakker et al., 2014).

Classic long life model with encouraged sufficiency - Advocates that products should strive for usage over an extensive time period, which in turn is enabled by continuous service, including repair and maintenance (Bakker et al., 2014). It embraces an non-consumerist approach where the customer should spend more for fewer products, i.e. it is a business model that slows down sales but enables a price premium and in general increases the customer's loyalty (Bockena et al., 2016). Together with the extending product value approach, this business model can be leveraged in the quest for slowing the resource loop.

Extending resource value - In this business model, firms should ensure that materials are brought back in a manner that it can be reused into new products (Blomsma and Brennan, 2017). This usually occurs at a product level. Similar to the case of slowing resource loops, it is although likely that gap exploiters exist which in turn profits from a well functioning take-back system where they later create new value sources of the reused material (Bockena et al., 2016).

Industrial symbiosis - A process oriented solution with similar rationale as the extending resource value approach, which both aims to close the resource loop. The major separator becomes that the waste in question for closing is in this case related to the process and not necessarily the product itself (Bockena et al., 2016).

3.3.3 Reverse Cycle

Business models that are slowing or closing the resource loops might require new partnerships in the value chain to take back products and materials in an efficient way. Large scale circular business models often require new collaborations and external partners in areas like manufacturing and distribution (Hopkinson, De Angelis, and Zils, 2020). In order to scale circularity, it is necessary to manage the reverse logistic network in order to overcome infrastructural gaps. Reverse logistic provides all the similar challenges as regular logistic activities, including scheduling, capacity constraints and storage costs. Above this, another layer of complexity is added due to factors as supply and demand uncertainty as well as often inadequate recycling networks on both a domestic and global scale (Lacy, Long, and Spindler, 2020).

3.3.4 System Enablers

This building block concerns how regulations and government directives can enable and increase the value created from circular economy, e.g. from favourable taxation and subsidies (Hopkinson, De Angelis, and Zils, 2020). However, since the focus of this thesis is on the actors in the automotive industry, and what they themselves can do to create value in the EOL process, system enablers are not analysed as thoroughly as the other building blocks.

4

Findings and Analysis

The following section will address the study findings in a chronological order similar to the presented research questions. Moreover, the section will combine findings with conducted analysis. For only the relevant study findings, see Appendix A.

4.1 Characteristics of the EOL Process

RQ1: What does the current end-of-life process look like given the interrelationships between all its identified stakeholders?

The first general finding regarding the initial material entering the EOL process, i.e. the cars, was that this actually can be categorised into one of two available alternatives. An EVL can either have reached its third and final life cycle stage as described by Kiritsis, Nguyen, and Stark (2008) by a natural reason, e.g. due to extensive usage over a significant time period. In this case, the vehicle can be referred to as a Natural ELV, or simply an ELV. The other categorization is commonly referred to as a Pre-mature ELV (P-ELV) or an Insurance Vehicle (IV), which includes a newer/more valuable vehicle that has been involved in some type of insurance matter (Engblom, 2020; Jensen et al., 2012; Kjartansson, 2020; Ljungkvist Nordin, 2020; Wikström, 2020). Since by definition, all vehicles handled by an insurance company are IVs but simultaneously not all these vehicles carry an extensive value (Eklund, 2020; Kjartansson, 2020), this thesis will distinguish between ELVs and P-ELVs, since the latter more clearly defines a vehicle that by an unnatural reason reaches its EOL. An exact definition of the difference between an ELV and a P-ELV has been hard to identify, although a rule of thumb according to Jensen et al. (2012) is that cars older than 10 years are deemed as ELVs. Moreover, when asked to describe factors that distinguishes a P-ELV from an ELV, Eklund (2020) explained it as,

> "We consider the age, condition and model of the vehicle. It could be that an older car with a stable demand is considered as a P-ELV whilst a new car with no demand is classified as an ELV".

Hence, it has been found that value related factors within the automotive industry, including age, mileage, condition and an active aftermarket for spare parts are factors that distinguishes between the two vehicle types. Table 4.1 provides an overview of the findings.

Table 4.1: Overview of the distinction between different EOL vehicles

Vehicle Type	**Description**
ELV	- Older vehicle, generally *more than* 10 years - No significant spare part value
P-ELV	- Younger vehicle, generally *less than* 10 years - Significant spare part value

Continuing, a natural question is to investigate the dispersion between the ELVs and P-ELVs. Statistics about this was found to be very thin, including major Swedish statistical data sources such as Bil Sweden, Statistiska Centralbyrån and Trafikverket. It became clear that an estimation needed to build upon findings from interviews with specific market knowledgeable actors, combined with the current market knowledge of scrapped cars in general. According to Stena Recycling, the main recycling actor for vehicles in the Nordics, and its employees Sverkman and Rosdahl (2020), approximately 200 000 cars are being scrapped in Sweden yearly, where 30 000 of these are Volvo ELVs whilst 10 000 are Volvo P-ELVs, see Figure 4.1 for illustration.

> "Around 200 000 cars are scrapped each year, where approximately 40 000 are Volvos. Amongst the Volvo cars, approximately 25% are so called Insurance vehicles" (Sverkman and Rosdahl, 2020).

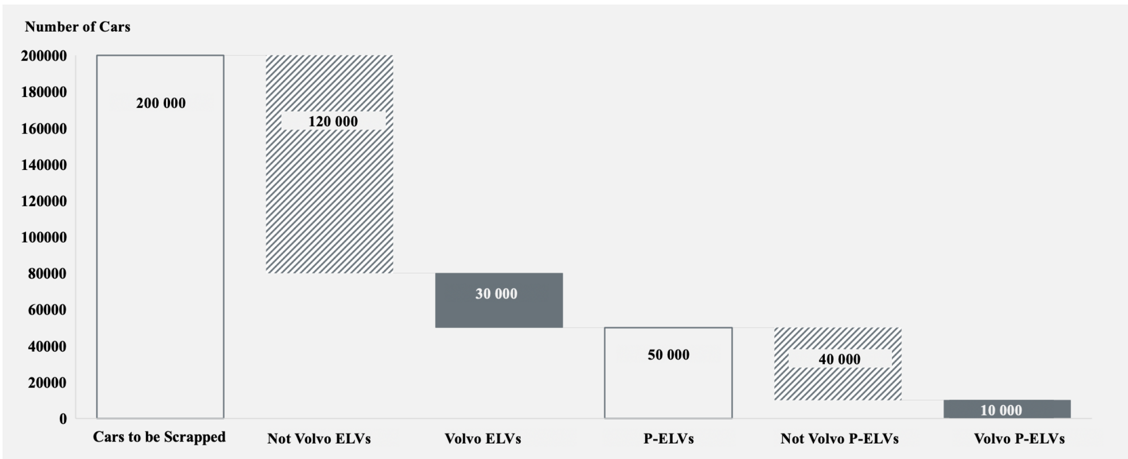


Figure 4.1: Dispersion of yearly ELVs/P-ELVs for Volvo Cars in Sweden

Furthermore, several interviewees argued that the EOL process consisted of five main stakeholders, namely *the Owner, the Insurance Company, the Repair Shop,* *the Dismantler* and *the Shredder*. The shredder is sometimes being referred to as the recycling company, or in some cases these roles are divided between two different companies (Wikström, 2020), in which case it becomes more evident of role differentiation. However, throughout this report, the final EOL stakeholder will be referred to as the shredder. Moreover, it was also found that the degree to which each actor is involved in the EOL process differs with respect to each vehicle type, where some stakeholders only are present in one of the mentioned processes. A more thorough description of the roles for each stakeholder will follow, although see Table 4.3 for an initial overview and explanation.

Subsequently, according to Jensen et al. (2012), the average weight for an ELV is approximately 1330 kg. Given that they in their analysis consider a wider range of vehicles than only Volvos, an estimation has been made on the average weight of a Volvo vehicle entering the EOL process, resulting in a benchmark weight of 1840 kg. This weight is based on the sales number and weight of each car model between the years of 2015 to 2019 and will be used as a benchmark for both ELVs and P-ELVs, although one could argue that cars sold in this interval does unlikely match the characteristics of an ELV. It is however, given the gray area between these vehicle types, still a more accurate parameter to build further analysis upon than the generic branch wide estimate provided by Jensen et al. (2012). Table 4.2 illustrates the *bottom up* estimation with respect to Volvo vehicles. The weight is based on an average for that vehicle type, which became the logic since each type often is present within a weight range.

Table 4.2: Estimation of average vehicle weight for a Volvo car

Model	**Sales (% of total)**	**Weight (ton/pcs)**	**Weight Factor**
V40	18%	1.45	0.26
V60	15%	1.90	0.29
V90	31%	1.45	0.59
S60	1%	1.85	0.01
S90	2%	2.00	0.05
XC40	8%	1.70	0.14
XC60	18%	2.00	0.35
XC90	7%	2.20	0.15
Total	**100%**	-	**1.84**

Table 4.3: Description of the involved stakeholder in the EOL-process with respect to each vehicle type

Vehicle Type:	*ELV*		*P-ELV*	
Stakeholder Name	Involved	Activity	Involved	Activity
Owner	Yes	Delivers the vehicle to a dismantling station free-of-charge (with conditions). Did earlier receive a scrapping premium, but it was removed as of 2007	Yes	Hands over the ownership of the vehicle to the Insurance Company after an insurance matter, given that the vehicle is condemned. Receives the market value of the car in return
Insurance Company	No	*Not involved*	Yes	Pays out the car market value to its owner if it is condemned. Thereafter, sells the car to a dismantler. Decides upon specification for which reused parts a repair shop can use for their insurance related errands
Repair Shop	No	*Not involved*	Yes	Receives the vehicle after the situation which caused the insurance errand. Makes an estimation of the damages and the associated costs to fix it. Also, the largest customer of reused parts from the dismantler
Dismantler	Yes	Receives the ELV from its last owner. Needs to accept this free-of-charge (with conditions). Ensures correct environmental treatment. Occasionally, dismanlte for spare parts and materials. Sells the car hulk to a shredder and spare parts to private persons or in some cases, repair shops	Yes	Buys the P-ELV from an insurance company. Ensures correct environmental treatment. Dismantle for spare parts and occasionally materials. Sells the car hulk to a shredder and spare parts to repair shops or in some cases, private persons
Shredder	Yes	Buys the car hulk from a dismantler. The car is then shredded into different fractions, where the major fractions constitute of valuable metals and materials whilst some are associated with disposal costs or are placed at landfills	Yes	Buys the car hulk from a dismantler. The car is then shredded into different fractions, where the major fractions constitute of valuable metals and materials whilst some are associated with disposal costs or are placed at landfills

4.1.1 Owner

In the case of an ELV, the last owner has the right to hand in the vehicle free-of-charge at any dismantling station in Sweden (SFS 2007:186, 2007). Previously, it existed a scrapping premium (*skrotningspremie*) which entitled the owner to a small monetary compensation for delivering the car to a dismantler. This was created in an attempt to incentivise recycling amongst the owners but although removed as of 2007 (Naturvårdsverket, 2019; Sverkman and Rosdahl, 2020). During more recent years, voices have been raised regarding the reenactment of the scraping premium in order to improve the recycle rate for vehicles (Motion 2017/18:246, 2017). Ljungkvist Nordin (2020) explained the ELV process from an owners perspective as,

> "For an ELV, it is the last owner that is responsible to submit the vehicle. This should although be free-of-charge and a dismantler should be available within reasonable range".

In the case of a P-ELV, the owner has an insurance company to which he or she pays a recurrent insurance fee, with the purpose of being reimbursed in the case of an accident. After interviews with Kjartansson (2020) at Länsförsäkringar, it was evident that there exist several alternatives for a owner with respect to insurance types, which in turn was seen as out of scope for this thesis. What although is noticeable is that the ownership of the car after a severe incident, i.e. an incident were the reparation cost is deemed too high compared to the cost of reimbursing the last owner (also referred to as condemning the car), is transferred to the insurance company. No interviews were conducted in which an owner was directly addressed regarding its role in the EOL-process. The rationale behind this decision was two-folded. Firstly, the average owner can be considered to have no value of an ELV whilst in the case of a PELV, it exclusively hands over ownership. Secondly, all interviewees were car owner's themselves and hence were able to understand the owner perspective as well. According to Uittenhout (2020), "When the last owner gets a certificate of destruction, they are free from responsibilities".

4.1.2 Insurance Company

When considering a natural ELV, an insurance company is not an important stakeholder since the reasons for why the car has reached its EOL is not often deemed to be insurance entitled. It although happens that cars being involved in an insurance claim has such a low market value, e.g. if they are very old or in extremely bad shape, that the insurance company does not charge the dismantler for handing over the possession. In the case of Eklund (2020), which is a major dismantling actor in Sweden based in Skövde, they described the dispersion of vehicle supply into their business in the following manner,

> "Insurance vehicles represents 95% of the business but within the insurance vehicles, there actually are quite a lot of ELV vehicles. The insurance company condemns the car anyway since it is such a low value. So in reality, 60% are insurance vehicles and 40% ELVs".

It should be noted that these numbers are not a generalization of how the supply deriving from the insurance companies is dispersed between ELVs and P-ELVs, but merely one objective. It although advocates the fact that the assumption regarding an insurance vehicle (IV), and that it per default should carry an extensive value, is misleading and hence the definition of a P-ELV is to prefer. Moreover, Sverkman and Rosdahl (2020) also advocated that the insurance company does not differentiate between ELVs and P-ELVs, but instead,

> "An insurance company that has condemned a car does not send it to a car recycling company but instead sends it to a car dismantler".

Considering a P-ELV, the insurance company manages several major events in the EOL process. For starters, it is the insurance company that determines if an automobile is worth repairing, and then by definition it has not reached its EOL. If considered relevant with a reparation, the insurance company has the right to determine what kind of spare parts to use (Kjartansson, 2020). When asked to define how much of a vehicle that is worth repairing, Kjartansson (2020) answered,

> "It is not possible to point out a specific divider between an ELV or an IV. Sometimes we repair up to 80% of the vehicle's market value, sometime we repair up to 100% of the market value. It will although seldom happen that we repair to a cost higher than 100% of the market value".

Moreover, if the vehicle is not repairable, the insurance company sells it to a dismantler. Depending upon the vehicle brand and region, there are different dismantlers that are interested in these vehicles, which in some cases creates a fierce competition for acquisition (Eklund, 2020; Engblom, 2020; Kjartansson, 2020; Wikström, 2020).

4.1.3 Repair Shop

Being merely an P-ELV stakeholder from the EOL process perspective, the repair shop is heavily connected to the business of an insurance company. This can be argued to be the case in two stages, starting of with that the vehicle involved in an insurance errand is being disposed at the repair shop after the incident. In this case, it is the repair shop that makes an estimation of how much the total cost of labour and materials will be and hence provides basis for the insurance company to make its repair versus scrap decision (Eklund, 2020; Kjartansson, 2020). Kjartansson (2020) explains it as,

> "The customer is in contact with us almost directly after the incident in order to clarify whom to blame for the accident and so on. Thereafter, the car ends up at a repair shop and it is decided upon what to do with the car. It is from this stage forward that my department is involved".

The repair shop is also a stakeholder in the sense that their business segment is the largest customer towards the spare part business of dismantlers. According to Jensen et al. (2012), 75% of a dismantlers spare parts are demanded from the repair shop, whilst 25% are sold towards private persons. This was also indicated by both Wikström (2020) and Eklund (2020), when describing the relationship their dismantling businesses have with different repair shop stakeholders. One reason for why repair shops acquire such a vast majority of dismantlers' supply of spare parts could be derived from the fact that they are required to imply reuse if possible, in cases where an insurance company pays for reparation. It is common that an insurance company only is required to exchange a broken part with one of equivalent quality (Kjartansson, 2020), which clearly illustrates the logical reuse connections between a dismantler, a repair shop and an insurance company. A slightly simplified example could be to consider a gear box that breaks down in a car that has driven 9000km. In that case, all reused gear boxes deriving from cars that has driven less than 9000km are considered as acceptable spare parts in the view of an insurance company and should hence be prioritized above virgin or remanufactured gear boxes.

4.1.4 Dismantler

In order to conduct business in a legal and transparent manner, a dismantler needs to be authorized according to SFS 2007:186 (2007), which in turn is made by Länsstyrelsen in each particular county. If authorized, a dismantler is obliged by law to handle all kind of ELVs that they receive in a safe and environmental friendly manner without charge. Exceptions can although be made in cases where the vehicle lacks some parts that are deemed valuable for a dismantler, e.g. engine or catalyst. In such a case, a dismantler can charge the last owner in order to provide a certificate of scrapping (SFS 2007:186, 2007). Moreover, the European Commission has decided upon guidelines regarding how far the largest possible distance to a dismantler is allowed to be with respect to the last owner's place of residence, which according to the guidelines should not exceed 50 km. Its member countries are although in turn allowed to bend these rules somewhat in order to fit the demographic and geographic conditions of that particular country (Directive 2000/53/EC, 2000; SFS 2007:185, 2007; Uittenhout, 2020).

> "An automotive company has the legal obligation to provide dismantling opportunities within a 50km radius from every owner. This can though be negotiated otherwise at a national level" (Uittenhout, 2020).

Sweden has several hundred of authorized dismantlers distributed across the country, which all are connected to the dismantling network called *BilRetur*, an association that ensures that the recycling goal of 95% is reached. Together with the Swedish Dismantling Association (SBR) and Stena Reycling, Bilretur constitutes the collection system for car manufacturers (Bilretur, 2020; SBR, 2020). The fact that the dismantler is one of the most important stakeholders in the EOL process has been emphasised by several non-dismantler interviewees, e.g. Sverkman and Rosdahl (2020),

> “Swiftly speaking, there are three main industries involved. It is the car producer, the car recycling company and the dismantler”,

> “The actual ELV process can be said to start when the car is delivered to a dismantler”,

or in the words of Engblom (2020),

> “To achieve the ELV directives is not an easy task. For this, we are going to need both the dismantler and the shredder”,

> “The dismantler and we as the car producer should have a cooperation. This is something I will fight for!”.

Although it exist dismantlers that manages a wide range of car brands (Eklund, 2020), it is still common amongst dismantlers that manages P-ELVs to specialize themselves towards a couple of car brands (Sverkman and Rosdahl, 2020; Wikström, 2020). Given that the P-ELVs still carry significant value, the competition for acquisition has put a clear value of specialization in terms of cost and disassembly efficiency. For a Volvo manufactured car, it exist seven major players that has divided the country in order to manage the vast majority of Volvo P-ELVs. Several of these also handles Renault and Dacia. These seven dismantlers have joined forces under a common database storage called BEGO (*an abbreviation of the Swedish words: Begagnat Ekonomiskt Garanterat Orginal*), where private persons can access all spare parts available within their common storage (BEGO, 2020). Other dismantlers also have the right to tender with insurance companies for the ownership rights of a Volvo P-ELV, although the BEGO community currently acquires the majority (Eklund, 2020; Wikström, 2020).

Whilst at the dismantler station, the vehicle enters a systematic dismantling process. Some of the activities are stipulated by law (SFS 2007:186, 2007) whilst others are carried out from a monetary business perspective (Eklund, 2020; Wikström, 2020). After general administration procedures, the first activity for both an ELV and a P-ELV is the environmental treatment. During this stage, the vehicle is treated according to the directives of (SFS 2007:186, 2007), including emptying of dangerous liquids, e.g. petrol and oil. Moreover, the dismantler also neutralize the car of components such as batteries, glass, tyres and catalyst. Continuing, the vehicle is transferred to a dismantling station where spare parts, if possible, are collected. This is done based on sales data as well as an experience driven approach on which parts that can be expected to experience a current and/or future demand. During the interviews with dismantling actors, it seems like focus is slowly shifting from the experience based approach to the more data driven approach. Eklund (2020) explained it from their perspective as,

> “We are better in terms of dismantling with the new data systems. Previously, we had to scrap parts, but now, we are a lot more accurate”.

Wikström (2020) touches upon similar aspects when explaining how they work with data,

> "We have a data system that keeps statistics over our business. It helps us predict future demand and thereby be more accurate in dismantling. In that way, we limit the amount of components that are being thrown away".

Moreover, in the case of Eklund (2020), it was found that they also have created an internal cooperation between several Swedish dismantlers. The purpose of this cooperation is to help each dismantler to fulfill their responsibility towards the insurance companies in terms of providing parts whilst simultaneously enabling lower inventory levels. This is accomplished by a transparency between each actors inventory levels and a zero additional cost transaction between the network actors. In that way, the dismantlers are enabled to scale up their ability to meet demand without scaling up their internal storage (Eklund, 2020). Furthermore at Swedish dismantlers, the process of dismantling spare parts is almost exclusively done manually by an operator. The tools available for conducting the dismantling are a combination of general tools, such as crowbar and screwdriver, as well as more specific tools, either created by the dismantlers themselves or by the actual car producer (Eklund, 2020; Wikström, 2020). In the experience of Engblom (2020), there exist potential in developing more sophisticated tools for dismantling. He argued that,

> "The major problem with ELVs is that you do not have the time to dismantle for material. Our special tools for dismantling were something we called a parrot scissor, which we made ourselves, and a smaller scissor for cabling".

The view of Engblom (2020), that it is often cumbersome to dismantle for material, especially without more sophisticated methods, was shared both by Wikström (2020) and Eklund (2020). Considering the amount of spare parts collected, this usually vary significantly between vehicle types, with a ELV only providing a handful of usable parts whilst a P-ELV not seldom provides over a 100 usable parts. After the car has passed through the environmental treatment as well as being striped of its parts and whatever material that was possible to separate, which in the case of a P-ELV can be up to 20% of the total car weight (Sverkman and Rosdahl, 2020), the remaining hulk is sold to a shredder (Eklund, 2020; Wikström, 2020). Different dismantlers have different approaches in this matter. Some sells the hulk as it is without any extensive dismantling of materials, whilst other attempts to separate different material types in order to increase the selling price (Eklund, 2020). It is evident after several interviews with dismantlers that they receive a higher selling price for more separated materials, but that the increase in labour costs for extensive dismantling is often higher than this premium and hence the general approach is to sell the hulk as one piece (Wikström, 2020). When the vehicle reaches the dismantling stage, the ownership transfers from the insurance company, in the case of a P-ELV, or the owner, in the case of an ELV, to the dismantling stakeholder. For the latter, the dismantler usually does not pay the owner, which became a natural result of the removal of the scrapping premium. Instead, the fact that the owner is guaranteed a safe and correct dismantling process is seen as payment enough. In the consideration of a P-ELV, the procurement is derived as mentioned from insurance companies according to a pre-negotiated percentage of the car's market value before the insurance errand begun.

4.1.5 Shredder

In comparison with dismantlers, there are significantly less shredders active in Sweden. According to Bäckström (2020), Stena Recycling is the largest and together with a handful other shredders, they make up the majority of the Swedish scrap market. When an ELV or a P-ELV arrives at the recycling facility, the first step is to shred the vehicle into smaller pieces. This is usually done by a large rotating wheel, after which the shredded material arrives at a sorting belt. From here, the material undergoes a range of sorting activities in order to separate it into as clean fractions as possible. This can be done through fans that collects lighter materials, commonly referred to as shredder light fraction (SLF). In the context of a car, this could be pieces from the seats, wood panels or smaller plastic fractions. With the help of big magnets, the recycling facility can collect ferrous materials, which mostly is iron. The non-ferrous material, commonly referred to as NF and including copper, aluminium and a heavy metal mix, is sorted out through different water baths with a shifting density. The remainder of the shredder fraction that is not sorted into any of these categories is referred to as fines, and include gravel and organic material, which also is collected with the usage of fans. These fractions combined makes out the material recycling part of a shredder facility. In terms of a car, it is stipulated according to Directive 2000/53/EC (2000) that the material recycling should at least be 85%. Continuing, a mix och light and heavy plastics together with inseparable materials goes into energy recovery, which implies that it can be used for example heating through incineration (Bäckström, 2020; Sverkman and Rosdahl, 2020). The remainder of a car's material ends up at landfills, which again according to the Directive 2000/53/EC (2000) is allowed for a maximum of 5% of the cars initial weight. Figure 4.2 illustrates the fraction dispersion of a car from one of Stena Recycling's facilities. It is noticeable that plastic is not found within any of the clean fractions from the shredding process. This is multifaceted phenomenon, including reasons such as a mixture of several plastic sorts at component level and not sufficiently good techniques for a clean sorting without downgrading. It has been found that the shredders abilities to properly recycle is correlated to the degree of available advanced techniques (Engblom, 2020; Ljungkvist Nordin, 2020; Material Economics, 2017; Sverkman and Rosdahl, 2020). Moreover, it could of course be reasonable to argue that the outcome in terms of material from an ELV and a P-ELV would differ, based on that a P-ELV has 20% less material than an ELV when entering the shredder facility (Sverkman and Rosdahl, 2020). It has although been cumbersome to find any output from this EOL stage that distinguish between the two vehicle types, which arguably is a result of that the facilities usually mixes the material inflow between the two vehicle flows. Sverkman and Rosdahl (2020) explains the vehicle's flow through the shredder facility as,

> "Many of the cars enter our fragmentation facility where they get processed. A big mill fragments the car into little pieces, which in turn enters the recycling facility".

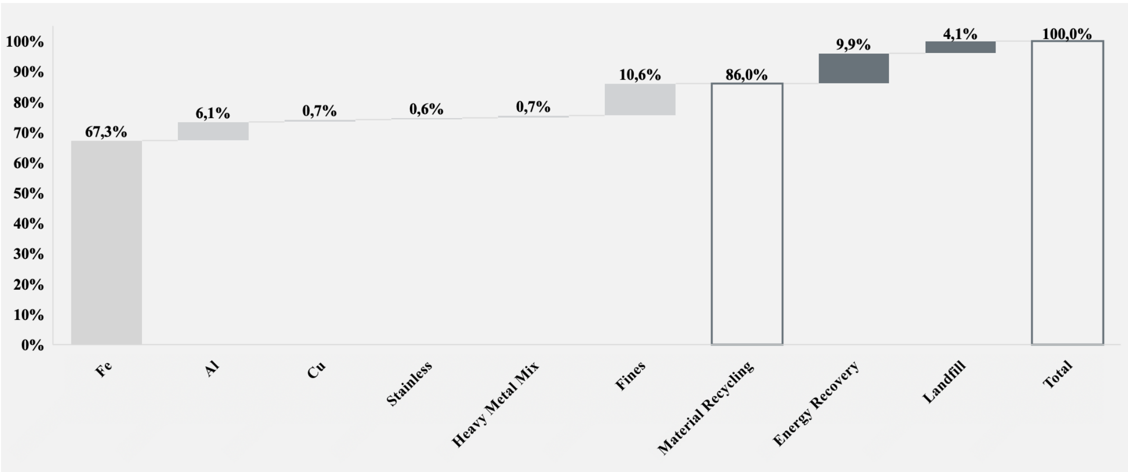


Figure 4.2: Shredder fraction output from a the recycling of a car (Sverkman and Rosdahl, 2020)

According to Sverkman and Rosdahl (2020), the quality of the recycled iron is "99.5% clean iron and can go directly into new steel production". Moreover, Sverkman and Rosdahl (2020) also argues that "our process (Stena Recycling) even gets a price premium on our iron fraction because it is of such a good quality". Considering the aluminium fraction, they argue that their own smelters have the capabilities to take aluminium fractions and convert it into procurement materials for suppliers to the car industry. In terms of the positive environmental impact that a car recycling process has, given that it is able to oblige under current car recycling legislation, Sverkman and Rosdahl (2020) argues that,

> "For every car that we recycle, we are able to save a CO2 amount equivalent of one years emission during that car's usage".

Moreover, during the interview with Sverkman and Rosdahl (2020), one reoccurring discussion theme was the need for scale in order to conduct business at a car recycling facility. Several quotes strengthened this, e.g.

> "It is impossible to develop a recycling process such as this one if you do not get enough volumes",

> "In order to get any value out of the recycling for cabling, it requires quite substantial volumes",

> "You really need a large scale, quality throughout the whole process and you need to acquire volumes in a way that you can manage them in the right way".

It was found cumbersome to provide a generalized picture of the customer base for the recycled fractions. The recycling companies seems to leverage their customer stock, both at an international as well as a domestic level, together with the current world prices for material and logistic costs (Bäckström, 2020; Sverkman and Rosdahl, 2020). In a Swedish context, it was found that almost 45% of all iron scrap is exported, whilst the rest is bough by domestic actors (Material Economics, 2017). As mentioned, much of the aluminium, in the case of Stena Recycling, is processed at their own smelters and then sold directly into different value chains. This is however not a general finding for car recycling companies, given that it requires a substantial investment in order to handle such a major part of the recycling process. A more generalized approach would be that the customers for car fractions are producers of raw materials, which in turn depending upon quality aspects, processes and sells the material into value chains. Moreover, in a Swedish context regarding the biggest shredder fraction from a car, i.e. iron (Fe), a major stakeholder at the customer side is *AB Järnbruksförnödenheter* (JBF). This is an organisation, owned by some of the biggest steel producer in Sweden including SSAB, Sandvik and Ovako, that centralize the procurement of iron fractions from recycling companies. In the words of Bäckström (2020), the CEO of JBF,

> "By collaborating regarding procurement, we are able to lower the logistic costs and secure that each steel mill get the right mix of scrap. What we try to do is to optimize the scrap we have in Sweden but also the imported scrap. Our main method of doing so is to ensure that we use the most efficient transportation methods and distances for each scrap grade and steel mill".

Bäckström (2020) argued that the logistic cost can make up as much as 10 to 15% of the item's value, and hence it is evident regarding the value of such an arrangement. Bäckström (2020) also emphasised that "if one consider CO2 emissions, it is not possible to neglect the transportation because this constitutes of a major part of the final emissions for recycled material". In terms of circularity, Bäckström (2020) further claimed that,

> "Steel is something that has been circular for a long time. I would say that it is one of the best examples of a circular economy. You can melt it down in eternity. It is only a couple of percentages that disappear in rust and similar but in general, it is constantly circling".

This claim is strengthened by Material Economics (2017) that advocates steel being the most recyclable material, and that 90% of all steel that falls out of use in Sweden is recycled. The reasons for the good conversion rate of steel could be that it is easy to sort out with magnets, it carries a high material value and it is fairly easy to re-melt into steel with similar abilities (Material Economics, 2017). However, it is common that steel over time will experience some degree of downgrading for each recycling cycle. This is often caused by an increased substance of non-iron material, commonly copper. In order for the downgrading iron to achieve desirable abilities, it can be diluted with virgin material. How severe the downgrading will be is in general connected to the efficiency of the recycling facility and/or the EOL process (Bäckström, 2020; Material Economics, 2017; Sverkman and Rosdahl, 2020).

4.2 Value Creation and Capture

RQ2: What monetary value is created and captured during the current end-of-life process with respect to each stakeholder?

The following section will be based upon the same logical sequence as in Section 4.1. It was however found that not all the identified stakeholders carries a substantial significance in terms of creating a monetary value in the EOL process. Of the five identified stakeholders, the two major value creators in terms of circularity are the *dismantler* and the *shredder*. This is fairly reasonable since they are the only actors that in an evident way brings value-added activities to the material available. However, it can be argued that the *repair shop* as well provides relevance in terms of installing the reused components. Although this being the case, they perform similar activities with the material being derived from the EOL process as if the material would be from virgin or remanufactured processes. Combining the findings from the first and second research questions, it is possible to map out each stakeholders' role in terms of monetary and material flow. Figure 4.3 illustrates the most important of these flows and is considered to be an overview of the most prominent findings.

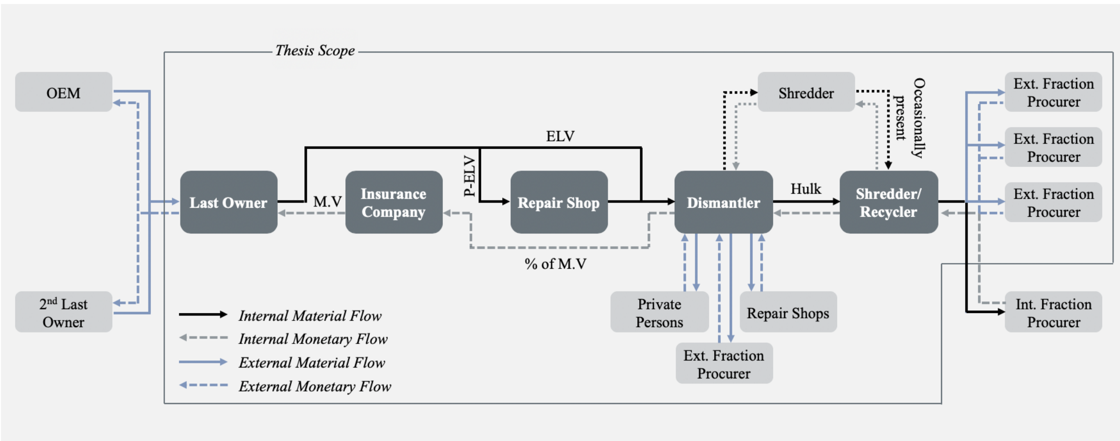


Figure 4.3: Overview of the EOL process for ELVs and P-ELVs

4.2.1 Owner

As indicated by the quote from Ljungkvist Nordin (2020) in section 4.1.1, the owner should be able to deliver its ELV to a dismantler free-of-charge. This is, according to SFS 2007:186 (2007), given that the vehicle is complete with components such as battery and catalyst. Otherwise, the owner could be obliged to compensate the dismantler in order to receive a certificate of destruction. It is however evident that from the current ELV perspective, the owner does not have any major sources of income and hence should be considered as a less important monetary stakeholder. Wikström (2020) also emphasised this fact by stating,

> “We are obliged to receive the ELVs from the car owner free-of-charge”.

Although from a P-ELV perspective, the owner could arguably be a monetary stakeholder given the fact that it pays recurrent insurance fees as well as receives the estimated market value (M.V) for the car in the case of an accident (Kjartansson, 2020).

4.2.2 Insurance Company

During the interviews with both Wikström (2020) and Eklund (2020), it was found that the dismantler pays the insurance company a percentage fee of the car’s current market value in order to acquire ownership of the vehicle. This percentage fee does generally not take into consideration if the vehicle is in particularly good or bad shape, although as indicated by Eklund (2020) “exceptions are made for very severe damages like fires that totally wrecks the vehicle”. The percentage fee has been negotiated beforehand, and are re-negotiated from time to time (Wikström, 2020). It was found throughout the interviews that the insurance companies seems to have a fairly comprehensive overview of the business model for dismantlers, and hence aims to set a price that is fair compared to the dismantlers’ average earnings for a vehicle. Kjartansson (2020) described this percentage fee in general terms as,

> “On average, our contract with dismantlers usually entitles us a compensation of 13% of a cars market value”.

Hence, it was found that although constituting the entire supply for P-ELVs, the insurance companies are a monetary stakeholder that value a good relationship with their dismantling counterparts.

4.2.3 Repair Shop

When buying a component from a dismantler, the repair shop in general receives a discount on the stated spare part price. This is something that the dismantler does in order to incentivize the usage of their specific parts as well as maintain a good working relationship with the repair shop (Eklund, 2020; Wikström, 2020). The insurance companies usually are well aware of this discount and the fact that the repair shops leverage this to improve their profit (Kjartansson, 2020). During the interview with Eklund (2020), he explained the phenomenon as,

> "If some part has a virgin price of 1000 SEK, we sell it for 500 SEK, that is accepted by the market. We then give some discount to the repair shop. This is done in good faith towards the insurance companies".

Hence, the repair shop is, as mentioned, a more important monetary stakeholder than the owner or the insurance company, in the P-ELV case. It has however no monetary involvement what so ever in the EOL process flows concerning ELVs.

4.2.4 Dismantler

The market for Volvo P-ELVs is according to Wikström (2020) divided between seven major dismantlers. In order to determine the monetary value for a P-ELV from the dismantlers perspective, an analysis had to be performed in combination with the findings.The yearly reports from the seven BEGO actors for the years 2016, 2017 and 2018 (a total of 21 yearly reports) have been used as the foundation for analysis. Continuing, the analysis has emphasised a *top-down* approach by firstly considering these seven actors' combined yearly revenue as a starting point. Furthermore, this number has been divided with the amount of P-ELVs that they are assumed to handle on a yearly basis. In order to maintain a more conservative estimate, an assumption has been made that these actors acquires and processes the entire share of P-ELVs presented in Figure 4.1, i.e. 10 000, although as indicated by Eklund (2020), there are other dismantlers in Sweden that as well acquires some share of the Volvo P-ELVs. Thereafter, a deduction was made based on the estimated income from the environmental treatment and the the hulk sale, made by Jensen et al. (2012), on a vehicle basis. Moreover, it was assumed that these three sources of income are constituting the total income for a dismantler, excluding financial incomes, something that was strengthened by Wikström (2020). The relevant numbers that are being used in the income analysis are presented in Table 4.4 whilst Figure 4.4 indicates the final income estimation for an average Volvo P-ELV based on the top-down approach used. According to the estimates from the top-down approach of the seven dismantlers, an average Volvo P-ELV is found to have an income potential of approximately 23 600 SEK from the dismantlers point of view. It is worth noticing that this is merely an income analysis and does not take any costs of either dismantling activities nor procurement into account. Moreover, Wikström (2020) touched upon yet another source of revenue for a dismantler that manages P-ELVs, namely the occasional sales of remanufacturing projects into Volvo's own remanufacturing business. These business opportunities occurs when a dismantler receives parts in such a condition that reuse is not an alternative, whilst the part is still in such a condition and demand that Volvo can profit from it in a remanufacturing perspective. In this case, Wikström (2020) argued that Volvo pays a higher amount for the broken part than a shredder would pay for the material. In terms of the final estimation value presented in Figure 4.4, the total value is not affected by this extra source of income, although the income associated with spare parts could be slightly lower and instead be allocated to the sales of remanufacturing projects.

Table 4.4: Numbers and estimates for the top-down approach to determine a dismantlers P-ELV income

Variable	Value (Unit)	Analysis Application	Source
Combined revenue	290 (Msek)	*Used as the foundation for the top-down approach*	Yearly Reports BEGO
Volvo P-ELVs	10 000 (pcs)	*Divisor for the combined revenue*	(Sverkman and Rosdahl, 2020)
Env.Treat. income	700 (sek/pcs)	*Part of the vehicle income, e.g. for catalyst and battery*	(Jensen et al., 2012)
Hulk income	1.3 (sek/kg)	*Part of the vehicle income when sold to a shredder*	(Jensen et al., 2012)
Car weight	1.84 (ton)	*Average weight of a Volvo car*	Estimate
Dismantled weight	20 (%/pcs)	*Weight of an P-ELV removed at dismantling station*	(Sverkman and Rosdahl, 2020)
Env.Treat. weight	12 (%/pcs)	*Weight removed during env.treat.*	(Jensen et al., 2012)

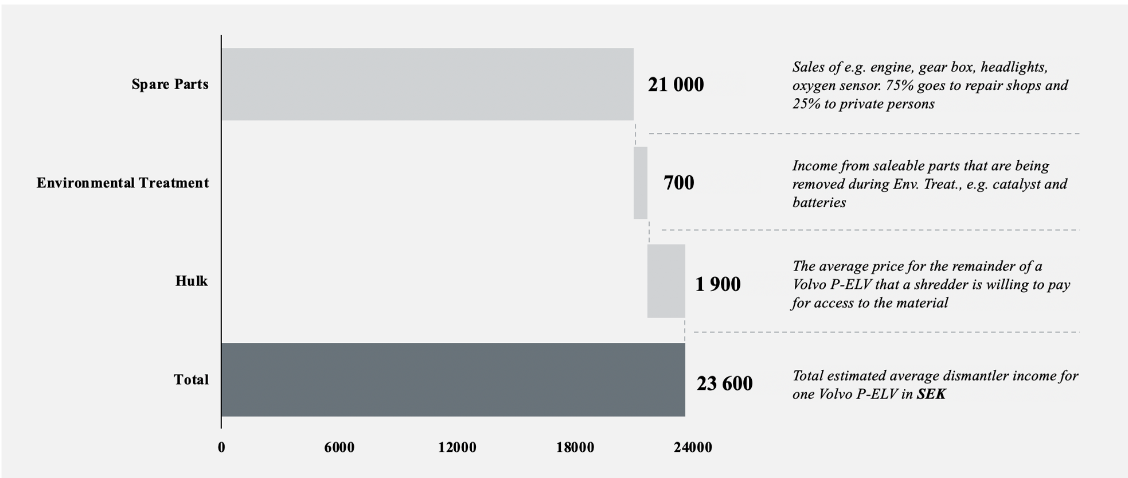


Figure 4.4: Break down of estimated dismantler income for one Volvo P-ELV

Subsequently, the income break down structure for an ELV from a dismantler perspective is to be found in Figure 4.5, resulting in an income of approximately 2 800 SEK. It is noticeable that the environmental treatment income is the same, given that it according to stipulated regulations requires that the same material is being treated. The hulk income is slightly higher, a natural result of that almost no spare parts are being removed and hence a heavier vehicle is sold to the shredder. In terms of spare parts, a fairly modest amount is usually collected from the average ELV although some exceptions exist. This could include cars with a vintage demand or still a stable but old average fleet. According to Wikström (2020) and Englblom

(2020), the general dismantler that focuses on P-EVL makes no profit on the ELVs, whilst Eklund (2020) claims that an increased focus on ELVs has resulted in their organisation profiting from the mentioned vehicle type. No findings have made it possible to estimate the income for spare parts in the ELV case, hence the N/A income in Figure 4.5.

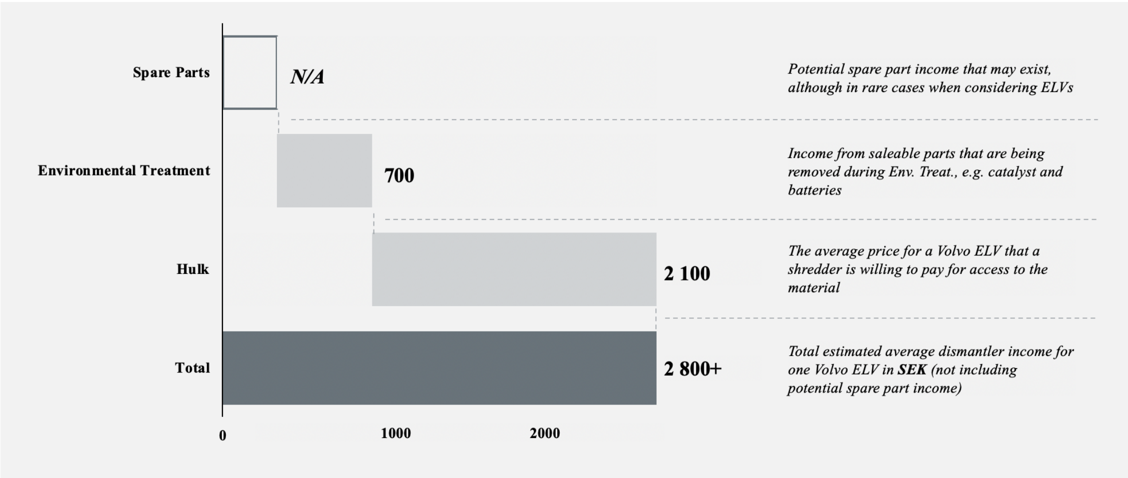


Figure 4.5: Break down of estimated dismantler income for one Volvo ELV

4.2.5 Shredder

In order to figure out the value a shredder derives from an ELV and a P-ELV, the logic became to follow the fractions presented in Figure 4.2 and to plot this towards the weight of an average Volvo ELV and P-ELV, after deducting the weight removed during the environmental treatment as well as potential spare part removal. The income estimate will in turn be derived from the market price of each fraction. In terms of iron and steel scrap, the Swedish market price is determined by JBF, which according to its CEO Bäckström (2020) "is mainly based on the current scrap price at the world market". However, iron and steel are not the only fractions affected by global market movements and commodity pricing. Almost all recycled material can be traded at a spot market (Material Economics, 2017) and thereby leaves little room for individual pricing from the shredders perspective. The fact that a shredder facility is highly dependent upon the market price fluctuation was further emphasised by Sverkman and Rosdahl (2020) when they argued that,

> "If the price for our commodity fractions goes down, this entire operation lacks complete cost coverage".

Given these findings, it is evident that the income estimate for the shredder fractions from a car will be highly dependent on each fraction's stated value. Table 4.5 reveals the values used for this analysis. Noticeable is that some fractions in fact generate no income, but instead carry different degrees of cost. These fractions are fines, energy recovery and landfill (Jensen et al., 2012; Sverkman and Rosdahl, 2020). Moreover, it was not possible to find a landfill price, nor the composition of the heavy metal mix, which in turn left these fractions without an associated price indicator. As indicated in Figure 4.2, all but energy recovery and landfill constitutes the material recycling of a vehicle, which according to the producer responsibility should be at least 85%. Also as indicated earlier, if one includes energy recovery to the recycling rate, the remaining car fractions that eventually are disposed at landfills, can not exceed 5% of the initial weight.

Table 4.5: Stipulated market value for the shredder fractions income analysis

Fraction	**SEK/kg**	**Comment**	**Source**
Iron (Fe)	+2.5	*Based on the findings of a secondary source*	(Jensen et al., 2012)
Aluminium (Al)	+17.6	*Al Primary (LMAHDS03) price average from 2/1-18 to 17/3-20*	Bloomberg Terminal
Copper (Cu)	+56.7	*Cu Primary (LMCADS03) price average from 2/1-18 to 17/3-20*	Bloomberg Terminal
Stainless Steel	+10	*Based on the findings of a secondary source*	(Jensen et al., 2012)
Heavy Metal Mix	*N/A*	*Consist of e.g. Mg and Zn. No price indicator was found*	-
Fines	**-0.4**	*Landfill coverage etc., yet a cost. Based on the findings of a secondary source*	(Jensen et al., 2012)
Energy Recovery	**-0.9**	*Incinerated for e.g. heat. Based on the findings of a secondary source*	(Jensen et al., 2012)
Landfill	*N/A*	*Disposed at landfills with no identified price indicator. Likely a cost*	-

With the use of the identified fraction values, it is possible to construct an estimate for both the P-ELV and ELV, which in turn is presented in Figure 4.5 and 4.6. The estimation technique in question for these estimates was based on a *bottom-up* logic, which also provides an explanation for why e.g. Landfill does not have an associated income connected to its weight. Although leaving room for improvement, the estimate based finding with respect to shredder income become approximately 4 570 SEK for a Volvo P-ELV and 5 000 SEK for a Volvo ELV. Comparing these numbers to the findings from Jensen et al. (2012), namely that car fractions are estimated to a value of 3 900 SEK, both the Volvo P-ELV and ELV estimates are considerably higher. The rationale for this can be two folded, firstly explained by a higher average weight of a Volvo compared to an average ELV, and secondly, the more updated price indicators for Cu and Al compared to those used by Jensen et al. (2012) are higher.

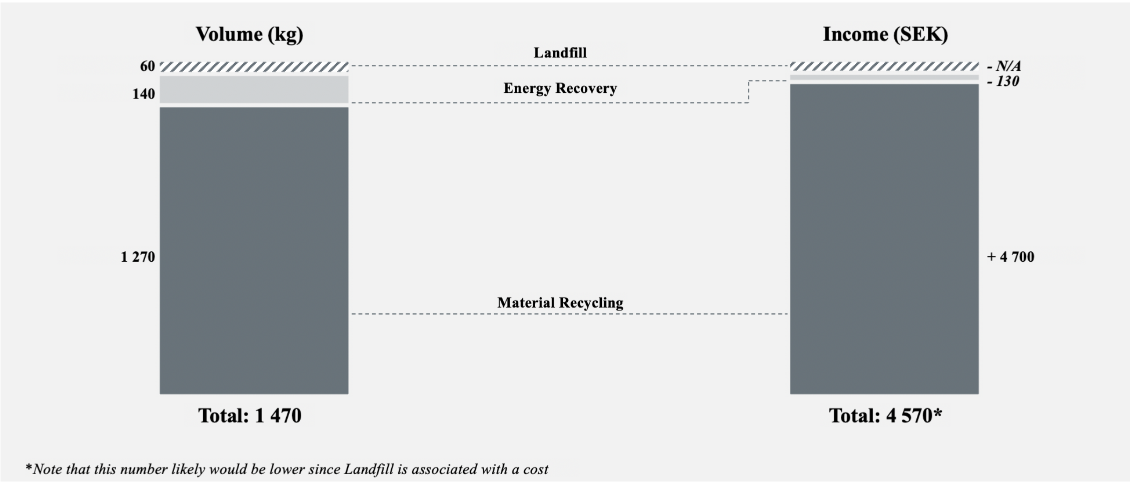


Figure 4.6: Estimated shredder income for P-ELV fractions

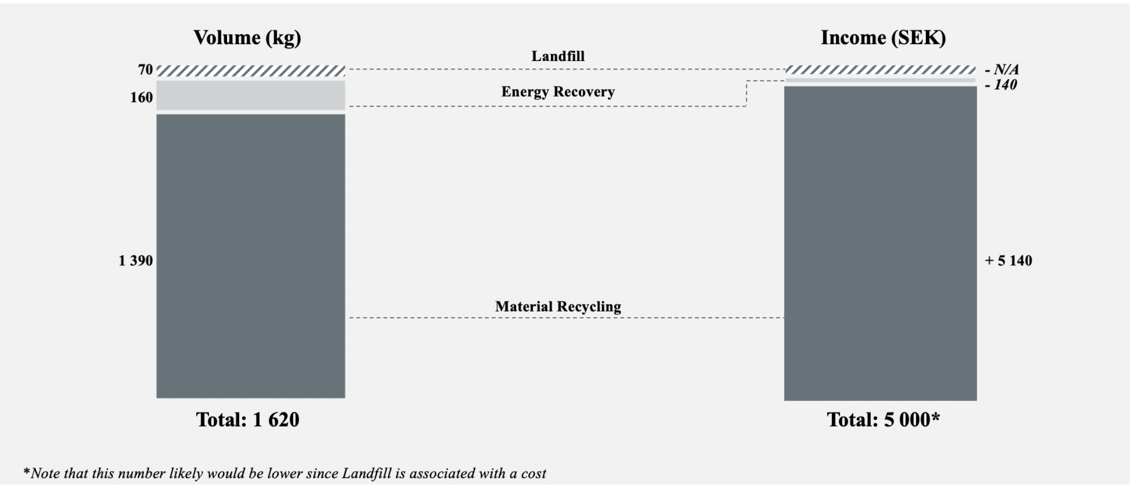


Figure 4.7: Estimated shredder income for ELV fractions

4.3 Value Added Activities

RQ3: In what way could the value for the end-of-life process increase? What are the barriers for doing so and what could be the role of an OEM in this process?

By conducting interviews, together with studying reports and articles, three action have been identified that could potentially increase the value of a vehicle in the EOL processes. The three actions are, (1) *apply circular design*, (2) *investigate the possibility of a more structured market for dismantled parts and materials*, and (3) *complement the manual dismantling process with mechanical dismantling.* Down below, the three actions are described in detail, together with their potential as well as barriers.

4.3.1 Design for Disassembly

Circular design is an important factor in value creation within circular economy, see section 3.3, and one way to increase the circularity of vehicles would be to consider the EOL process already in the product development phase (Engblom, 2020; Material Economics, 2017). Engblom (2020) states that,

> "Reuse and recycling must be considered already in the stages of product development, design and production".

One type of circular design is called Design for Disassembly (DfD), and aims for easier disassembly process. In the case of vehicles, this would mean an easier dismantling. Easier dismantling could get two consequences: either (1) the dismantler can dismantle more parts from the car in the same time as before, or (2) the dismantler can dismantle the same amount of parts in less time than before (Andersson, 2020; Engblom, 2020; Wikström, 2020). The first consequence could hence increase the dismantler's revenue, while the second could reduce the dismantler's costs. It is hard to estimate the consequences of dismantling more parts since the potential increase in income this could lead to is dependent on which extra parts that would be dismantled, and how the demand for these parts would be. The same logic also applies when considering a potential increase in dismantled material. Nevertheless, how DfD could affect time of dismantling has been studied, and from that it is possible to draw conclusions regarding its effect and if it is significant to the a dismantlers cost or not.

4.3.1.1 Potential for Design for Disassembly

After analysing the annual reports for the three latest years from the BEGO dismantlers handling Volvo P-ELVs, it could be concluded that cost of personnel represents on average 36% of a dismantler's total cost. In addition, according to Wikström (2020), labour cost connected to dismantling for spare parts represents a "clear majority" of the personnel cost. If that is a general fact for most of the dismantlers, it would be safe to state that labour cost connected to dismantling represents at least 50% of the cost of personnel. Combining those two insights, it could be argued that since labour cost connected to dismantling represent at least 50% of the personnel cost, which in turn represents 36% of the total cost, labour cost connected to dismantling would represent at least 18% of the total cost for the average Volvo P-ELV dismantler.

If the labour cost connected to dismantling represents at least 18% of a dismantler's total costs, a reduction in the time it takes to dismantle a car, and thereby a reduction in labour cost, could have a quite significant impact on the dismantler's total cost - and hence also on the dismantler's EBIT. It was found by Soh, Ong, and Nee (2014) when conducting a DfD study in the automotive industry, where a display panel was disassembled with ordinary design and disassembly compared to DfD-strategies, that DfD could have a time saving for dismantling display panels on up to 55%. Based on this, it could be argued that DfD could have a significant and positive impact on dismantlers' EBIT. Figure 4.8 illustrates how the average EBIT margin for the BEGO dismantlers could change, based on the two shifting variables available, namely share of labour costs associated with spare parts dismantling and time reduction due to DfD when dismantling these parts.

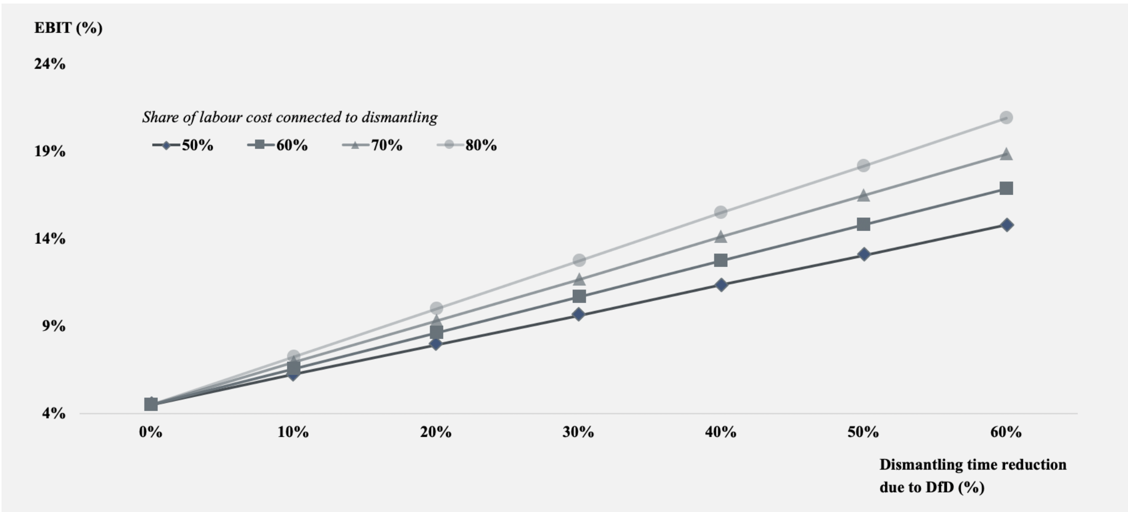


Figure 4.8: Simulation of how different degrees of DfD and dismantlings share of labour costs could affect dismantler EBIT

4.3.1.2 Identified Barriers

Through interviews and reports, three major barriers regarding DfD have been identified: (1) the OEM that design the cars, in this case Volvo Cars, would not get any additional value from DfD, (2) it requires specific knowledge concerning the dismantling process and its environmental effects, and (3) it can require extra resources in terms of time, staff, and money.

The first barrier concerns incentives. The OEM is the actor that designs the vehicles, but their customers would not pay more for a car that is better designed for disassembly (Andersson, 2020; Houston et al., 2020). Hence, the OEM would not get any additional value from DfD in the situation equivalent to that of Volvo Cars. Instead, the potential value that would come from DfD would be realised and captured first at the EOL stage, where the OEM in general has no control over the vehicles. Andersson (2020) carries a belief that development in areas like DfD is likely to come from legislation, since that would give the OEMs actual incentives. Looking at the EU directives regarding ELVs, it is stated that the car manufacturers are obliged to make sure that the cars can be recycled to at least 85%, and that the environmental treatment is done before the vehicles enters the recycling stations (Directive 2000/53/EC, 2000). However, regarding preventive actions, the directives tells the member states only to encourage vehicle design that takes into account and

Table 4.6: Identified barriers for implementing Design for Disassembly at OEMs

Barrier	**Description**	**Source**
No additional value to OEM	*The OEM's customers do not seem willing to pay more for a circular design and the OEMs lack capabilities to collect the value at EOL*	(Andersson, 2020)
Specific knowledge	*Specific knowledge is required regarding the dismantling process, and which tools and methods that could be used when implementing DfD*	(Engblom, 2020)
Extra resources	*Implementing a more circular design might require additional resources for the OEMs in terms of money, staff and time*	(Andersson, 2020)

facilitates easier dismantling, reuse and recycling (Directive 2000/53/EC, 2000). A stricter legislation connected to DfD could therefore be one way to increase incentives for OEM's.

The second and third barriers are described by both Engblom (2020) and Andersson (2020). Regarding the implementation of DfD in the automotive industry, specific knowledge about environmental issues more generally, which methods to use when implementing design changes, and how the dismantling process works would be needed. Engblom (2020) explains this, and describes an example of how he let a group of employees from the product development department dismantle a car and how they were "astonished over how unnecessary difficult some design features made the dismantling process".

Andersson (2020) further present "extra resources" as a barrier to implement DfD. Extra resources could be in terms of more staff needed, or that implementing DfD might be time consuming, or in terms of economical resources (Rossi, Germani, and Zamagni, 2016). This barrier in combination with the first one described, that OEMs in the described situation captures no additional value from designing their cars for disassembly, could end up making the implementation of a circular design to a costly action.

4.3.2 Structured Market for Parts and Materials

There are examples of circular business models where old, used materials and parts from vehicles are sold back to suppliers. This has been found to be happening in the German automotive industry for many years already, according to Tostar (2020) who also explains that Volvo has received offers for similar arrangements. According to Almen (2020), there exist actors, other than repair shops and shredders, that are interested in materials from the EOL process for vehicles that not necessarily must be of a fraction character.

4.3.2.1 Identified Market Opportunities

During the interviews, it was found that potential buyers for parts and/or materials from EOL vehicles likely already exist within suppliers to the automotive industry. Moreover, it was found that other value chains, not automotive related, also have showed interest for the material at hand. Considering in-house OEM activities, it was further emphasised that Volvo Cars' own remanufacturing business, with logistics centre in Maastricht, has the potential of leveraging from the EOL process. Considering automotive suppliers, Tostar (2020) advocates that they to a greater extent are tapping in to the EOL process for materials in several other European countries than Sweden. Carvid (2020) also advocated the fact, arguing that even recycled plastics, something that barely has any value in the Swedish market, are bought from dismantlers in other countries. The following quotes were found relevant to the findings,

> "For many years, suppliers in the German automotive industry have been buying back dismantled parts and materials" (Tostar, 2020),

> "In Belgium, there is a demand for the plastics that could be dismantled from vehicles, in contrast to in Sweden where there are almost no buyers" (Carvid, 2020).

If the cost of buying back a dismantled part and doing a simple remanufacturing, or perhaps just cleaning of it, is less than the cost of producing or buying a new part, this scenario offers a potential cost reduction for the supplier as well as an opportunity for the dismantler to increase revenues. This can potentially also include damaged parts (Green, 2020; Wikström, 2020). A good example of the potential value that could come from arrangements like this is a Swedish foundry, and supplier to the truck industry, that offered to buy old disc brakes from Volvo Cars for a significant price premium compared to the price that the shredders would have given for the material (Almen, 2020).

Considering actors in other industries that as well have showed interest regarding the materials and parts from ELVs/P-ELVS, Tostar (2020) describes how a German producer of premium polymers expressed interest in buying headlamps from Volvo's ELVs or P-ELVs, to get access to the headlamps' high quality PC plastics. In addition, Volvo Cars has initiated discussions with other companies regarding potential collaboration when it comes to other materials and parts, e.g. the high quality leather from within the cars, that could be used in industries such as the clothing and bag industry (Strömberg, 2020). Arrangements like these have the potential to create a demand for dismantling non-spare parts, and thereby a demand for an extended dismantling, as long as the price for the dismantled parts and materials is higher than the cost of dismantling them (Wikström, 2020).

Many automotive OEMs have a remanufacturing business, that provides an alternative to virgin parts but with similar quality. In Volvo Cars' case, their remanufacturing business has a logistics centre located in Maastricht, Netherlands (Green, 2020). There, Volvo Cars has an exchange terminal, where repair shops from all over Europe sends torn and broken parts. The parts are then either scrapped, sold as material, or remanufactured. The remanufactured parts are then sold back to repair shops and private persons as spare parts, for the same price as original parts (Green, 2020). Volvo does not differ between original parts and remanufactured parts when sold, given that the quality of the remanufactured parts are at least the same as the original parts, the buyers do not even know if they buy a remanufactured part or an original part (Green, 2020). Employees from Volvo Cars have conducted business cases for remanufacturing parts (Green, 2020) and from that, they have got price factors for the parts. The price factor is a number, calculated by the cost of remanufacturing the part divided by the cost of buying a new part. For some parts, it is more expensive to remanufacture them than to create new virgin parts. For these, the price factor is exceeding 1.0. However, for the vast majority of parts, the price factor is below 1.0. For these parts, Volvo Cars could get a significant cost reduction from remanufacturing parts instead of buying new parts (Green, 2020). According to Green (2020), the remanufactured parts are yet still a minority of the total amount of spare parts provided, if considering the combined sale with virgin parts.

4.3.2.2 Identified Barriers

To enable new markets, there are different barriers that have to be overcome. Except from usual business barriers, e.g. ways of communication and payment, more specific factors for the automotive industry are enough scale in terms of number of vehicles, a more structured way of matching buyers and sellers, and a better collaboration between the OEM and the EOL actors.

Table 4.7: Identified barriers for a larger secondary market

Barrier	**Description**	**Source**
Scale in vehicles	*Hard to find profitable business opportunities without many vehicles due to variation*	Several interviewees
Lack of matching	*No structured way for the suppliers to procure EOL materials and components directly from the OEM*	(Almen, 2020; Tostar, 2020)
Lack of collaboration	*A gap between what suppliers require versus to what degree they can leverage the material from EOL actors*	(Tostar, 2020)

Mutual factors that influence all the identified circular business alternatives are the need to reduce variation and the need for reverse logistics. A sufficient scale in terms of vehicles can aid in overcoming these obstacles and to make it more profitable (Otterheim, 2020; Strömberg, 2020; Tostar, 2020; Westerdahl, 2020). From the perspective of a circular economy, logistics around high value products and materials, as in the case of OEMs, are often more problematic for the profitability than for the environmental impact. In other words, there is a higher risk that the logistics would make the circular business efforts non-profitable rather than non-environmental friendly (Bäckström, 2020; Otterheim, 2020; Westerdahl, 2020). Why the logistics probably would not remove the environmental benefits is explained by Otterheim (2020) below,

> "When it comes to materials such as for example aluminium and steel, the spread between virgin and recycled materials in terms of CO2 footprint is so big that I don't believe that the logistics would remove the environmental benefits from initiatives like that".

Tostar (2020) further emphasised the fact that financial aspects often provides a bigger obstacles for a circular economy than environmental aspects when saying,

> "It is the economy that is hard to capture in terms of increasing the use of old material, e.g. with car bumpers. If considering Sweden, it is the labour cost that mostly prevents much of this. From an environmental point of view, there is no problem".

Another potential barrier is presented by Almen (2020), who describes that Volvo Cars does not have a structured way to find business opportunities in cases where they control EOL material, e.g. with a Swedish foundry that wanted to buy disc brakes. Instead, ideas like that are generated ad hoc, mostly by own initiatives from employees at Volvo Cars or external actors. In addition, Volvo Cars did not know that the foundry was interested until Volvo Cars themselves called the foundry and asked them (Almen, 2020). Therefore, it is likely that there may be several actors out there interested in paying a premium for parts like the disc brake (Almen, 2020; Tostar, 2020). A third potential barrier for ELVs and P-ELVs business opportunities is the lack of control and collaborations between the OEM, suppliers and the EOL actors. Considering the circular business opportunity connected to the headlamps of ELVs, this was never realised since Volvo Cars has no control of their vehicles whilst at EOL (Tostar, 2020). Volvo Cars traditionally loses control of their cars the moment they sell them, something that although may change over time given their new, more subscription based, business models with CbV and M (see section 2.2.1). The fact that a more structured scrap market for materials such as aluminium and steel is needed, is also strengthened by Material Economics (2017). They argue that that it is necessary with a better overview on where and how much scrap is generated, and a better matching of different actors' supply and demand, to keep the high quality aluminium and steel alloys, similar to the arguments from Tostar (2020) and Almen (2020).

4.3.3 Mechanical Dismantling

Mechanical Dismantling is a process where an operator manages an excavator-like vehicle, specially designed for dismantling vehicles. In general, this machine has the possibility to remove larger car parts, such as doors, seats and roof, as well as smaller components and cabling. It is however not capable of removing spare parts for reuse (Eklund, 2020; Jensen et al., 2012; Ljungkvist Nordin, 2020; Wikström, 2020). In contrast to Sweden, where this method is only used by a few dismantlers, mechanical dismantling is already widely established in Japan (Eklund, 2020; Material Economics, 2017). In the quote below, Eklund (2020) describes that his dismantling company currently manages to separate many times more copper and aluminium, before sending the car to the shredder, than they used to do before they started with mechanical dismantling,

> "In 2016, we separated copper and aluminium manually, and manage to separate around 0,3 and 8,4 tonnes respectively that year. In 2018, we used mechanical dismantling and managed to separate around 32 and 218 tonnes respectively."

On a vehicle basis, these numbers implied according to Eklund (2020) an increase of almost 12kg copper and 105kg aluminium per piece. A question was raised after the identification of mechanical dismantling, namely how the shredders looks at more material being removed at the dismantler stage, given that a shredder's income is highly connected to the sale of fractions. Some shredders that possess advanced separation methods are able to separate the copper and aluminium themselves. Usually, these actors are not willing to pay the same amount for a vehicle where the copper and aluminium have been removed as to compared with a complete hulk (Eklund, 2020). However, some shredders do not have that advanced separation methods, and therefore pay the same price per kilo for the vehicles regardless if the copper and aluminium are removed or not (Eklund, 2020). The shredders that cannot separate the copper actually get more value out of the iron from the vehicles if the copper is separated before shredding, since the shredding otherwise mixes the iron and copper, something that causes a downgrade in the quality of the iron. Downgrading materials is bad both from an economic and an environmental perspective (Bäckström, 2020; Material Economics, 2017). During the interview with Bäckström (2020), he at several times returned to the problem of copper within recycled steel, as emphasised by the following quotes,

> "We actually do not see that much extra value in virgin scrap versus used scrap. A problem we although have noticed is that it, over time, copper is accumulated into used scrap. The current processes are not able to separate as much copper as desirable when it comes to more advanced steel grades, and therefore one needs to add some virgin scrap and mix this with used scrap in order to lower the degrees of copper",

> "If it is possible to improve the separation of copper in the EOL process for a car, that would help recycled steel",

> "If scrap is dirty and polluted, the price will be lower. If it is too dirty and polluted, we do not even want it",

> "There exist a negative circular effect in not separating copper. You both pollute the iron and simultaneously loses the copper value".

As indicated by the quotes from Bäckström (2020), the prices per kilo for copper and aluminium are many times higher than the price per kilo the shredders pay for the vehicles, which also is strengthened by the findings in Table 4.5. When combining these insights, it was found that as long as there exist shredder actors that are willing to pay the same price per kilo for acquiring the hulk, no matter if the copper and aluminium have been removed or not, a dismantler can increase the value for each vehicle by separating copper and aluminium. These fractions can then be sold to a higher amount to external fractions procurers. No analysis has been made in the case where the shredder lowers the average hulk price, which makes it impossible to draw further conclusions on how a dismantler should act in those cases.

4.3.3.1 Potential of Mechanical Dismantling

To estimate the potential impact of mechanical dismantling on a dismantler's income, an analysis of the income, alternative costs, and additional labour cost has been conducted, based on the findings from the interview with Eklund (2020). The "losses", illustrated in Figure 4.9, in copper and aluminium are the income that they would have generated as a small additional weight in the average hulk price when sold to the shredder, whilst the copper and aluminium income is based on their average price per kilo (see Table 4.4). The additional cost from increased labour is based on the additional ten to fifteen minutes it takes to separate the materials, together with an average operator cost of 600 SEK an hour (Jensen et al., 2012).

Table 4.8: Findings regarding the effect of mechanical dismantling

Variable	**Value (Unit)**	**Analysis Application**	**Source**
Additional Cu	11.88 (kg)	*Net amount of extra copper dismantled through machinery*	(Eklund, 2020)
Additional Al	105 (kg)	*Net amount of extra aluminium dismantled through machinery*	(Eklund, 2020)
Labour cost	600 (sek/h)	*Cost of one operator per hour*	(Jensen et al., 2012)
Operator time	15 (min)	*Net amount of extra time required to use the machine*	(Eklund, 2020)

Together with previous findings regarding income for different fractions and the findings summarized in Table 4.8, the mechanical dismantling analysis was able to be conducted and is presented in Figure 4.9. The scenario is based on an ELV, although the same analysis is able to scale towards a P-ELV as well. The resulted material income for an ELV from a dismantlers perspective was found to increase from 2100 SEK to 4300 SEK, equivalent to over a 100%.

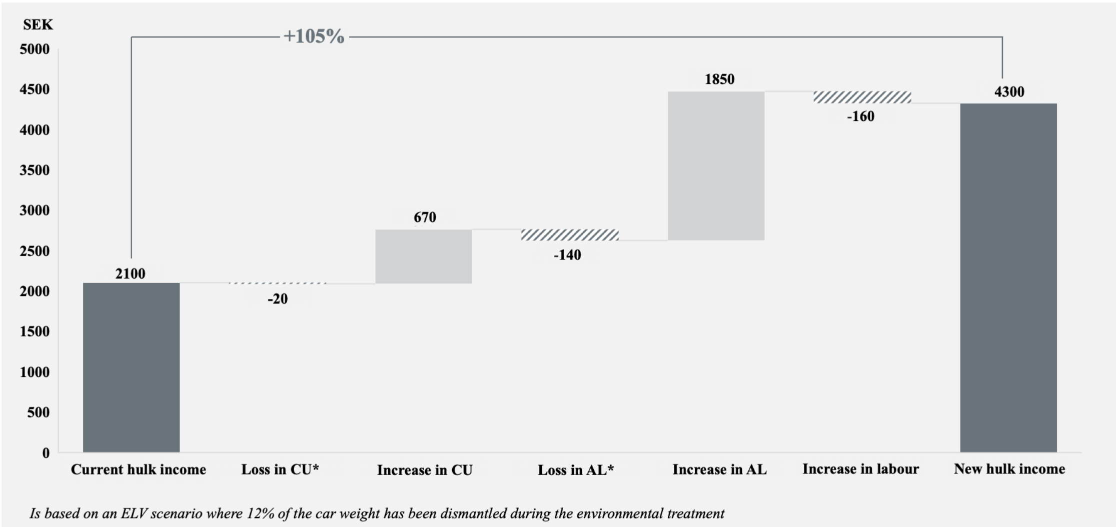


Figure 4.9: Potential increase in a dismantlers hulk income from mechanical dismantling

4.3.3.2 Identified Barriers

In order to prosper in the business of mechanical dismantling, it was found that one need to overcome barriers in terms of scale and skills as well as find business synergies from the proposed actions.

Table 4.9: Identified barriers for mechanical dismantling

Barrier	Description	Source
Scale	*A substantial amount of vehicles are required in order to achieve a reasonable ROI*	(Eklund, 2020)
Skilled operators	*The efficiency is interconnected to the skills of an operator, which requires time to be developed*	(Eklund, 2020)
Business synergies	*Less evident of the business value for material if the core abilities are focused towards spare parts*	(Wikström, 2020)

Of all interviewees, Eklund (2020) was the only one with actual experience of conducting mechanical dismantling at EOL vehicles, and hence the most suitable to share his experience of potential barriers. In his experience, scale in terms of yearly numbers of vehicles is the main barrier for achieving business success with mechanical dismantling. Eklund (2020) argues that,

> "You require some volume in terms of cars. In order to manage the associated investment, at least 2 000 yearly vehicles are required".

Moreover, Eklund (2020) states that there is a need for employees that are skilled enough to handle the machine. He argued that a clear trend can be detected between the amount of material separated each year, something that in turn can indicate some kind of learning curve in terms of the ability to separate the materials from the vehicles. It could also be argued that this learning curve also applies to the time required for a mechanical dismantling. Furthermore, when asked about why his dismantling business did not invest in mechanical dismantling although being one of Sweden's largest dismantlers, Wikström (2020) argued that his business segment in terms of supply, i.e. mostly P-ELVs, and their core business of removing and selling spare parts, had few synergies with mechanical dismantling. It could also be argued that given the profitability of spare parts, as illustrated in Figure 4.6, the increased hulk income from mechanical dismantling seems less attractive for a P-ELV actor.

4.4 A Broader Perspective of the Role of an OEM

The findings and analysis has throughout the thesis been from the perspective of Volvo Cars, which makes sense given the selected research strategy of a case study. It is although fair to assume that other OEMs within the automotive industry have different approaches towards their EOL involvement. Through meetings and interviews at Volvo Cars, it is understood that *Renault Group* (RG) is one of the more actively engaged OEMs in the EOL processes. Therefore, a brief investigation into what RG is doing in the EOL stage has been conducted as part of the study findings.

Considering RG, they are already engaged in the EOL processes, through partnerships with EOL actors as well as their own EOL subsidiaries and remanufacturing plant (European Commission, 2014). RG's remanufacturing plant in Choisy-le-Roi is yearly remanufacturing around 15 000 engines, 20 000 gearboxes, 30 000 injection pumps and 3 500 cylinder heads (Ellen MacArthur Foundation, 2012). At the plant, 43% of the parts received are remanufactured, and 48% are recycled in RG's own foundries to be used in the production of new cars (Ellen MacArthur Foundation, 2012). Besides the remanufacturing plant, and an established collaboration with a large french recycling company called Suez Environnement, RG has two subsidiaries within the EOL business. This includes (1) INDRA - a large dismantling network, and (2) Gaia - a company with the purpose of coordinating the various actors in the EOL process by buying materials and parts recovered from ELVs in INDRA's network, then contract recyclers to recycle these materials and finally resell them to RG's plants and suppliers (Renault Group, 2018). In addition, RG initiated an European Commission Life project called ICARRE95 in 2010, that lasted until 2015, with the goal to increase the upcycling of EOL vehicles (European Commission, 2014). The project included collaboration with many EOL actors such as Hensel Recycling, MTB Recycling, and Synova to improve the upcycling of different parts and materials (European Commission, 2014).

5
Discussion

The following section will begin by discussing the circularity aspects of the current EOL process, together with the suggested value adding actions, in the context of the presented theory. Subsequently, the discussion will cover the identified aspects of value creation and capture, with a concluding section of these concepts from the viewpoint of a circular economy and what the role of the OEM could be.

5.1 Current Impact on Circularity

During the investigation of the stakeholders' involvement in the current EOL process, it is arguably only the dismantler and shredder that, to a major extent, contributes to higher degrees of circularity. The rationale behind this is that these actors are the only ones performing value adding activities with respect to the EOL material, i.e. the ELVs and/or P-ELVs. As mentioned, a repair shop conducts similar activities with both virgin as well as reused or remanufactured material, and hence has no particular importance in terms of ensuring a more circular EOL flow. It is however an enabler, e.g. for reused parts to end up in a vehicle being repaired. If considering the insurance companies, the fact that they regularly promote the usage of reused components also makes them an enabler for the flourishing of a circular process, although not a contributor in terms of value adding activities. In the context of the current stakeholder structure, the investigated OEM do not significantly contribute to an increased circularity of the material in the EOL process. The fact that the OEM provides guidelines for dismantling and to some extent also tools, enables several other stakeholder activities but they do not perform any value adding activities for ELVs or P-ELVs in terms of second life. However, given that the study has identified other OEMs that have a higher degree of involvement in the EOL process, it is cumbersome to draw general conclusions about all OEMs' impact on circularity based on one case company.

Moreover, if considering the different circular loop types described by Bockena et al. (2016), it is evident that merely referring to the current constitution of the EOL process as a closed loop is misleading. From a P-ELV dismantler perspective, the main business activities were found within after market for reused spare parts. Given that this particular activity enables a second life for parts that otherwise would have been disposed, it is arguably an activity that is *slowing* the loop rather than anything else. In situations where a dismantler collects and sells materials for second usage to external actors, it could arguably be considered as an action that aids in the *closing* of the loop. The two loop types are not mutually exclusive at the dismantling stage, but can rather coexist and hence making its business activities very desirable from a circular standpoint. Furthermore, to require a dismantler to aid in activities connected towards narrowing the resource loop is unfair, given that such enabling actions are occurring upstream from the dismantler. Hence, a dismantlers main activities in the current automotive EOL structure actually aligns with much of the preferable state of circular economy. This is particularly true if considering the mature market for reused spare parts in the P-ELV case. Considering the material aspect, there exist room for improvement when it comes to separation of different fractions, and thereby enabling a more closed loop system with a lower risk of downgrading. If considering the second life alternatives as presented by Gharfalkar, Zulfigur, and Hillier (2016), it is evident that several alternatives exists between reuse and recycle, which are the two major alternatives that currently are present in terms of circularity from a dismantling perspective. Given that a P-ELV has been condemned by the insurance company due to damages, several components exist in such a shape that they can not be reused but still have potential of being repaired, refurbished or remanufactured. All these alternatives are preferable from the standpoint of a circular economy and hence should be leveraged as such. However, it is unlikely that dismantling actors can manage all these activities by their own, especially considering the resources required for remanufacturing and that Houston et al. (2020) advocates that high investment costs usually conducts an in-house barrier for circularity. Hence, it is identified as a gap in the current EOL process, in which an OEM can aid, in order to both provide business value but also ensuring that the right secondary hierarchies are being leveraged to the extent possible. The OEM could thereby enabling a secondary market, and thereby also overcome another of the circularity barriers presented by Houston et al. (2020).

If targeting a cradle-to-cradle cycle for the automotive industry in accordance with the theories from Braungart, McDonough, and Bollinger (2007) and Lyle (1994), it will be necessary to enable an efficient recycling for all components and/or material that can not undergo more efficient circular economy activities, such as reuse or remanufacturing. The study has identified some Swedish dismantlers that to some extent themselves perform separation activities for materials. It can although be concluded that in order to fully recycle an automotive, the investment costs for the required facilities are so substantial that it is unlikely for a dismantling actor of current size to carry these. Hence, the shredder is needed in the quest for closing the loop, both from a post-consumer but also from a post-society viewpoint as presented by Wells and Seitz (2005). Depending upon the shredder's abilities, it can *slow* as well as *close* the resource loops. The rationale behind the presence of the former is correlated to the concept of downgrading, i.e. the inability to create recycled fractions of such a quality that it is equivalent to the initial virgin fractions. It was found in the study that although the recycling abilities are improving among automotive shredders, they still downgrade a substantial amount of the material. Hence, the shredder has improvement potential for both increasing the recycling rate but also to more efficiently recycle in order to avoid downgrading. This would benefit in terms of a more extensive closed loop for automotives as well as a more desirable second life hierarchy, with a decrease in recovery and landfill.

5.2 Impact on Circularity from Proposed Actions

Considering *Design for Disassembly* (DfD) in the context of circularity, it has the potential of simplifying the dismantling process. This could enable an increased dismantling for parts and/or materials, resulting in an increased circularity. Given that dismantling activities have been indicated as time consuming, it thereby decreases the ability of, e.g. material separation at the early stages. Given the more comprehensive dismantling DfD may cause, it in turn can unlock the market for selling cores to repair, refurbish or remanufacturing instead of recycling. An increase in material separation also have the potential to address the concept of downgrading, and provide higher quality fractions for shredders. Hence, there is a clear circularity value of DfD and it aligns with the theory of circular design presented by Hopkinson, De Angelis, and Zils (2020) and Lacy, Long, and Spindler (2020).

Capturing the *market opportunities* identified in Section 4.3.2.1 could lead to a more extensive dismantling for parts before going to recycling and being sold as fractions, incinerated or disposed. This would increase the circularity, namely because of reusing products is more resource efficient than recycling, again in accordance with Gharfalkar, Zulfigur, and Hillier (2016). In the cases where suppliers expressed interest in ELVs in order to access the materials, and not to reuse the parts, it could still be argued that this could have a positive impact on the circularity. Namely, if separating these materials before they enter the shredding process, it is possible to keep the materials from getting downgraded in the shredding or recycling process. This might not be the case for all types of materials, and also depends on what the buyer does with the material. Although, in those cases where separating materials before the shredding process minimize the risk of downgrading, the circularity is increased, with a closed loop potential spanning all from internally to a post societal spectra. Also, it would enable a solution to the value chain barrier of secondary market. If combined with DfD and with the possibilities of leveraging the existing logistic network within the industry, several of the major circular value chain barriers identified by Houston et al. (2020) have the potential of being overbuilt for the automotive industry.

If it is better from a circular perspective to separate materials such as copper and aluminium through mechanical dismantling compared to advanced recycling processes, has not been investigated in this study and is hence hard to draw conclusions from. However, in the case where dismantlers sell their cars to shredders that cannot separate these materials, mechanical dismantling will likely have a positive impact on circularity. It therefore has the potential of increasing the closed loop rate as compared to the slowed loop, due to the potentially cleaner fractions. In the context of a regular sized Swedish dismantler, it will however be a significant investment, and hence the barrier of high investment costs associated to circularity are in all essence present.

5.3 Who Creates and Captures the Value Today?

Regarding the ELVs, it is the dismantler and the shredder that performs all value adding activities and hence create *use value*, described by Bowman and Ambrosini (2000) as value that is created by labour within the organisation. Considering the owner, it has no control in regards to how their cars are treated during the EOL process, and is therefor not creating any value. For P-ELVs, it can also be argued that it is mainly the dismantler and the shredder that creates value, by extracting valuable parts and materials from the vehicle. However in addition, both the repair shops and insurance companies are involved in the EOL process for P-ELVs. It could be seen as if the repair shop creates use value to a small degree, by using dismantled parts while repairing cars. For the insurance companies, it is hard to motivate how they actually create use value in the EOL process, since they do not perform any value-adding activities on their own. Instead, it could be described as if the insurance companies contribute to creation of value by forcing the repair shops to use reused parts when available and hence increasing its demand. Consequently, this gives the dismantlers incentives to create more value by dismantle more parts.

To understand who captures the value, one can look at the *exchange values*, i.e. the price being paid (Bowman and Ambrosini, 2000). As stated in section 4.2, the insurance companies sets an exchange value for P-ELVs that are considered fair from both theirs as well as the dismantlers perspective. However, it could be argued that the insurance companies are in a quite good negotiation position since they possess the supply of P-ELVs, which some dismantlers rely heavily on for income. To connect back to the theories of relative bargaining power, described by Bowman and Ambrosini (2000), one could say that the P-ELV dismantlers do not have many possible substitutions if aiming for an extensive spare parts business and hence, this creates a theoretically desirable bargaining power position for the insurance companies. Regarding the relation between the dismantler and the repair shop, the repair shop captures a small part of the P-ELVs value in the shape of the discount they receive from the dismantler. However, given that the insurance companies occasionally requires for the repair shop to buy reused parts, this may weaken the repair shops bargaining power versus the dismantlers. This occurs due to a decrease in available procurement options, given the exclusion of virgin substitutes, and is hence heavily connected to the specific part's current reuse supply. In situations where the supply is large amongst suppliers, a repair shop can still have some degrees of market power and hence negotiate a more beneficial discount for the spare part in order to boost profit. Regarding the shredders' involvement amongst P-ELVs, they are not in a position to capture a majority of the value, given that the hulk of the car just represents a small part of the total value. In terms of ELVs, the shredder both creates and captures the majority of the value. Since the shredders are not dependent only on vehicles, and are fewer in numbers than the dismantlers, it is likely that the shredders are not dependent on a specific dismantler to supply them with vehicles. This will make it hard for dismantlers to take very high prices for both the ELV and P-ELV hulks.

5.4 Who Creates and Captures Additional Value?

Given that the OEMs designs the cars, they are key figures regarding the implementation of a *design for disassembly.* Therefore, it is the OEMs that create the potential value increase from the implementation of DfD. Regarding the identified market opportunities, it is not obvious who will be the actor creating this potential value. It will likely require some kind of collaboration between the OEM, the dismantler and the potential buyers in regards to informing each other about the supply, demand and specifications for parts and materials. Implementing mechanical dismantling would be done by the dismantler and thereby they are the ones responsible for creating this additional value.

All three of the proposed actions could have the consequence that there would be a higher demand, or a cheaper way, to increase the amount of parts and materials dismantled. Naturally, this means that the dismantlers are in a good position of capturing the increased values from the proposed actions. However, there is a possibility for the insurance companies to capture parts of the created value as well. Factors such as ownership of the P-ELV supply, awareness of the dismantlers profitability and in general larger organisations, would enable the insurance companies to leverage their market power relationship against the dismantler, if connecting back to the theories about who captures values by Bowman and Ambrosini (2000) and Lindgreen et al. (2012). Hence, it is likely that the P-ELV price required of the insurance company, i.e. the exchange value, would increase if the proposed actions are implemented. However, based on today's situation where the insurance companies and dismantler negotiate prices they both consider fair, a situation where the insurance companies are capturing all the value would unlikely incentivise the implementation of the proposed actions amongst the dismantlers. Hence, it is likely that the dismantlers are able to capture parts of the increased value. Neither the owner nor the repair shop are likely to capture any extensive additional value, although it may be desirable for dismantlers to pay for ELVs in a similar manner to the previous scrapping premium, and hence enable for the owner to capture some value. Considering the shredder, the proposed actions may result in a lighter hulk and hence a decrease in value capture. It may although also provide cleaner fractions and thereby an increase in value. Hence, it is hard to draw specific conclusions regarding the actions effect towards the shredding business.

5.5 Circularity for Automotive Value Creation

Considering how the four building blocks for value creation in circular economy, presented by Hopkinson, De Angelis, and Zils (2020), fits into the automotive industry, the theoretical aspects have been compared to the study findings. *Circular design's* possibility to create value in a circular sense within the automotive industry is clearly strengthened throughout this study. Several interviews and secondary data sources advocates its importance, e.g. through easier and less costly dismantling for parts and materials together with purer material compositions. The fact that *Design for disassembly* was identified as a proposed value adding factor, and that DfD is a subcategory to circular design, amplifies the importance of circular design for the industry's circularity, both in the current state but also in order to develop.

In the automotive industry as whole, and not EOL processes in particular, several indications exist of how *new business models* can increase the industry's circularity. Actions connected to car sharing and subscription, exemplified in Table 2.1, have the possibility to both narrow and intensify the resource loop, hence clearly aligning with theories about circular economy (Bockena et al., 2016; Geissdoerfer et al., 2018). However, regarding the EOL process, new business models have the potential to increase the values created as well. This has been exemplified through the finding of how a *structured market* for secondary materials and parts both can have a positive impact on income as well as circularity.

The stated theory that *reverse network management* is a necessary building block for value creation and capture within circular economy was found to be true for the particular case of the Swedish automotive industry. It is in all essence an enabler for the identified market opportunities to prosper, as well as obtaining any value from the identified circular design methods. If factors such as reverse logistics are not in place for the EOL activities, many EOL business models will be difficult to motivate monetarily, given the challenges of controlling costs and having a sufficient scale in terms of vehicles.

Much of the improvement in terms of the circularity for vehicles has been driven by domestic and international regulations. Hence, it can be concluded that *system enablers* is an important factor for increased circularity within the automotive industry. In terms of value creation, system enablers have not been found to create value in itself, but instead to provide incentives for actions such as circular design and DfD, hence enabling value creation for the process at hand.

During the study, it has been found that both at the dismantling and shredding stage, technological improvements have enabled increased value creation and circularity. At the dismantling stage, *mechanical dismantling* was identified as one technological improvement that, although carrying an investment cost, enabled increased profitability as well as purer material flows. It was however cumbersome to place mechanical dismantling amongst any of the stated building blocks for value creation in circular economy. For the shredding stage, it has been found that the most technologically advanced shredders manage to separate more materials in comparison with their competitors, and hence increasing both the value creation and the circularity of the entire EOL process for automotives. The most advanced recycling facilities have invested big amounts of money in order to separate as clean fractions as possible without downgrading, which still is not able to recycle all material and hence further emphasises the need for an even more extensive technological improvement within the area. Given the found importance of *technological enablers*, it could arguably be seen as a fifth and additional building block for value creation and capture within circular economy for the automotive industry. Without technological enablers, it would not be possible to achieve the ELV directives stated by the European Commission nor fully address the problem of downgrading. As the products, in this case automotives, are becoming more complex in its composition, it also requires for the recycling technologies to accelerate together with this development and hence further strengthens its relevance as a building block in value creation and capture for circular economy.

5.6 The Role of the OEM

Regarding circular design and DfD, the OEM's role can work both as a barrier and an enabler. As mentioned, the OEM has a central role in implementing DfD. If an OEM is not engaged in the EOL-processes that would benefit from DfD, as in the case of Volvo Cars, it likely lacks the incentives of changing the design since this can be costly and time consuming and the created value would only be captured by the EOL actors. If the OEM is engaged in these EOL processes, similar to the case of Renault Group, it can capture the values and hence have increased incentives to implement a circular design.

Considering new business models, it is likely that the importance of the OEM differs depending on which type of business model is discussed. Regarding re-sale and recommerce business models, these are existing in the automotive EOL-process already, without OEMs' involvement. The spare part business of dismantlers is one example of this. In order for the automotive industry to become circular within its operations, i.e. *internalisation*, it could be argued that an OEM actively engaged in the EOL process could be an enabler. Given that the automotive EOL actors are not producing any vehicles on their own, they cannot implement internalisation business models and are hence in need of an OEM's involvement. In a situation where a secondary market provides non-automotive value chains with materials, the importance of an OEM's involvement is likely lower.

For reverse network management, there currently are some reverse networks in place with respect to the identified EOL structure. With the help of an OEM, these could arguably be extended and improved. Considering Renault Group, they created subsidiaries to manage the logistics networks, which is a more extensive action than Volvo Cars currently is undertaking. Through tighter collaboration, an OEM not involved in the EOL process has the possibility to leverage ELV and P-ELV material, e.g. through potential remanufacturing exchange programs as in the case of Volvo Cars. These types of reverse networks would probably be difficult for small EOL actors to create by themselves, and thereby a collaboration with OEMs could be beneficial.

System enablers are something that does not seem very affected by the different role of OEMs in the automotive industry's EOL processes. Instead it could rather be argued that system enablers, such as the ELV directive, rather are affecting the roles of the OEMs than vice versa. However, it seems likely that OEMs taking a leading role in terms of circularity, could affect the decisions about directives, regulations and other system enablers.

Considering the presented *technological enablers*, such as mechanical dismantling, a sparsely or not engaged OEM has no control over implementation of such technologies. It can be implemented by the EOL stakeholders without the participation of any other actors. One possible way for OEMs to be part of the implementation could be to co-finance the machine with e.g. the dismantler. Financial aid from an OEM could help the dismantler overcome the barrier of a big investment cost. However, if the OEMs have incentives or not to engage in the implementation of technological improvements such as mechanical dismantling depends heavily on their possibilities of capturing values from it.

Based on the discussion above, it is evident that the role of the OEM affects value creation in circular economy. To what degree the OEM will create value is although heavily dependent on its possibilities to capture value. An OEM not involved in the EOL activities is likely to lack the capabilities of capturing EOL values, and thereby is unlikely to perform actions that enables an increase in the mentioned values. This has been found to be the case for Volvo Cars. In contrary, an OEM involved in the EOL process can capture the EOL values and hence has the incentive of creating them as well.

6 Conclusion

The purpose for this study was to provide a deeper understanding of the current EOL process, its stakeholders, and how value is created and captured combined with identified measures of how the EOL value and circularity of vehicles could be increased.

In terms of EOL materials, the study concludes that a categorization can be made with respect to EOL vehicles: End of Life Vehicles (ELVs), that generally are older than 10 years and carries a material value, and Premature End of Life Vehicles (P-ELVs), that generally are younger than 10 years and carries a material as well as spare part value.

The study concludes that the EOL process consists of five main stakeholders, including (1) owner, (2) insurance company, (3) repair shop, (4) dismantler and (5) shredder. In the case of P-ELVs, all these actors are present, whilst for ELVs, only the owner, dismantler and shredder are considered involved.

From a circularity perspective, the current EOL process mainly implies reuse and recycle. After investigating potential business opportunities, the study concludes that the stakeholders to a greater extent could leverage repair, refurbish and remanufacture of spare parts in order to become more resource efficient, and thereby reaching higher degrees of circularity.

In the current EOL process, the dismantler and the shredder were found to be the main value creators with respect to the EOL material. However, it has been concluded that in the P-ELV case, both the insurance company and the repair shops are enablers for value creation. Also, the ability to capture value is distributed amongst all four of these actors in the case of a P-ELV, and between the dismantler and shredder in the case of an ELV.

Regarding future research, there exist room for a deeper investigation into how DfD should be implemented in practice, including the most suitable parts, and to identify key factors for the enabling of a successful secondary market. Moreover, this study also opens up for further research into how the automotive market will leverage repair, refurbish, and remanufacture in a practical manner with the aim of becoming more circular. Future research may also investigate how the undergoing market changes, such as electrification and increased car sharing, will affect the current EOL process. One scenario worth investigating further is when OEMs initiate car sharing and subscription models, and hence automatically becomes the owner in the EOL process.

The study provides a theoretical contribution in terms of highlighting the importance of *technological enablers*. It is concluded that technological enablers can be seen as a fifth building block in the context of value creation and capture within circular economy for the automotive industry.

Another theoretical contribution provided in the study is that OEMs have the possibility to enable both increased circularity and simultaneously create values in the EOL process. However, the incentives for an OEM to take action on these opportunities are highly connected to its ability to capture the created values. This ability is in turn dependent on how involved the OEM is in the EOL process.

Considering practical contributions, it has been concluded that design for disassembly, mechanical dismantling and a more structured market for secondary parts and materials are measures that have the potential to increase both value and circularity of the EOL process for automotives.

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A

Appendix 1

This appendix will summarize the findings presented in section 4. Firstly, the quotes will be presented in the same chronological order as they appear in the report. From this, the identified measurements are presented according to the similar logic.

A.1 Quotes

> "We consider the age, condition and model of the vehicle. It could be that an older car with a stable demand is considered as a P-ELV whilst a new car with no demand is classified as a ELV" (Eklund, 2020)
>
> "Around 200 000 cars are scrapped each year, where approximately 40 000 are Volvos. Amongst the Volvo cars, approximately 25% are so called Insurance vehicles" (Sverkman and Rosdahl, 2020)
>
> "For an ELV, it is the last owner that is responsible to submit the vehicle. This should although be free-of-charge and a dismantler should be available within reasonable range" (Ljungkvist Nordin, 2020)
>
> "When the last owner gets a certificate of destruction, they are free from responsibilities" (Uittenhout, 2020)
> "Insurance vehicle represents 95% of the business but within the insurance vehicle, there actually are quite a lot of ELV vehicles. The insurance company condemns the car anyway since it is such a low value. So in reality, 60% are insurance vehicles and 40% ELVs" (Eklund, 2020)
>
> "An insurance company that has condemned a car does not send it to a car recycling company but instead sends it to a car dismantler" (Sverkman and Rosdahl, 2020)
>
> "It is not possible to point out a specific divider between an ELV or an IV. Sometimes we repair up to 80% of the vehicle's market value, sometime we repair up to 100% of the market value. It will although seldom happen that we repair to a cost higher than 100% of the market value" (Kjartansson, 2020)

"The customer is in contact with us almost directly after the incident in order to clarify whom to blame for the accident and so on. Thereafter, the car ends up at a repair shop and it is decided upon what to do with the car. It is from this stage forward that my department is involved" (Kjartansson, 2020)

"An automotive company has the legal obligation to provide dismantling opportunities within a 50km radius from every owner. This can though be negotiated otherwise at a national level" (Uittenhout, 2020)

"Swiftly speaking, there are three main industries involved. It is the car producer, the car recycling company and the dismantler" (Sverkman and Rosdahl, 2020)

"The actual ELV process can be said to start when the car is delivered to a dismantler"(Sverkman and Rosdahl, 2020)

"To achieve the ELV directives is not an easy task. For this, we are going to need both the dismantler and the shredder" (Engblom, 2020)

"The dismantler and we as the car producer should have a cooperation. This is something I will fight for!"(Engblom, 2020)

"We are better in terms of dismantling with the new data systems. Previously, we had to scrap parts, but now, we are a lot more accurate"(Eklund, 2020)

"We have a data system that keeps statistics over our business. It helps us predict future demand and thereby be more accurate in dismantling. In that way, we limit the amount of components that are being thrown away"(Wikström, 2020)

"The major problem with ELVs is that you do not have the time to dismantle for material. Our special tools for dismantling were something we called a parrot scissor, which we made ourselves, and a smaller scissor for cabling" (Engblom, 2020)

"Many of the cars enters our fragmentation facility where they get processed. A big mill fragments the car into little pieces, which in turn enters the recycling facility" (Sverkman and Rosdahl, 2020)

"99.5% clean iron and can go directly into new steel production" (Sverkman and Rosdahl, 2020)

"our process (Stena Recycling) even gets a price premium on our iron fraction because it is of such a good quality" (Sverkman and Rosdahl, 2020)

“For every car that we recycle, we are able to save a C02 amount equivalent of one years emission during that car’s usage” (Sverkman and Rosdahl, 2020)

“It is impossible to develop a recycling process such as this one if you do not get enough volumes” (Sverkman and Rosdahl, 2020)

“In order to get any value out of the recycling for cabling, it requires quite substantial volumes” (Sverkman and Rosdahl, 2020)

“You really need a large scale, quality throughout the whole process and you need to acquire volumes in a way that you can manage them in the right way” (Sverkman and Rosdahl, 2020)

“By collaboration regarding procurement, we are able to lower the logistics costs and secure that each steel mill get the right mix of scrap. What we try to do is to optimize the scrap we have in Sweden but also the imported scrap. Our main method of doing so is to ensure that we use the most efficient transportation methods and distances for each scrap grade and steel mill” (Bäckström, 2020)

“if one consider CO_2 emissions, its not possible to neglect the transportation because this constitutes of a major part of the final emissions for recycled material” (Bäckström, 2020)

“Steel is something that has been circular for a long time. I would say that it is one of the best examples of a circular economy. You can melt it down in eternity. It is only a couple of percentages that disappear in rust and similar but in general, it is constantly circling” (Bäckström, 2020)

“exceptions are made for very severe damages like fires that totally wrecks the vehicle” (Eklund, 2020)

“We are obliged to receive the ELVs from the car owner free-of-charge” (Wikström, 2020)

“In average, our contract with dismantlers usually entitles us a compensation of 13% of a cars market value” (Kjartansson, 2020)

“If some part has a virgin price of 1000 SEK, we sell it for 500 SEK, that is accepted at the market. We then give some discount to the repair shop. This is done in good faith towards the insurance companies” (Eklund, 2020) “is mainly based on the current scrap price at the world market” (Bäckström, 2020)

“The costs and revenues generated from ELVs are basically a zero-sum game for the dismantlers” (Engblom, 2020)

“If the price for our commodity fractions goes down, this entire operation lacks complete cost coverage” (Sverkman and Rosdahl, 2020)

“Reuse and recycling must be considered already in the stages of product development, design and production” (Engblom, 2020)

“astonished over how unnecessary difficult some design features made the dismantling process” (Engblom, 2020)

“For many years, suppliers in the German automotive industry have been buying back dismantled parts and materials” (Tostar, 2020)

“In Belgium, there is a demand for the plastics that could be dismantled from vehicles, in contrast to in Sweden where there are almost no buyers” (Carvid, 2020)

“When it comes to materials such as for example aluminium and steel, the spread between virgin and recycled materials in terms of CO2 footprint is so big that I don’t believe that the logistics would remove the environmental benefits from initiatives like that” (Otterheim, 2020)

“It is the economy that is hard to capture in terms of increasing the use of old material, e.g. with car bumbers. If considering Sweden, it is the labour cost that mostly prevents much of this. From an environmental point of view, there is no problem”(Tostar, 2020)

“In 2016, we separated copper and aluminium manually, and manage to separate around 0,3 and 8,4 tonnes respectively that year. In 2018, we used mechanical dismantling and managed to separate around 32 and 218 tonnes respectively” (Eklund, 2020)

“We actually do not see that much extra value in virgin scrap versus used scrap. A problem we although have noticed is that it, over time, copper is accumulated into used scrap. The current processes are not able to separate as much copper as desirable when it comes to more advanced steel grades, and therefore one needs to add some virgin scrap and mix this with used scrap in order to lower the degrees of copper” (Bäckström, 2020)

“If it is possible to improve the separation of copper in the EOL process for a car, that would help recycled steel” (Bäckström, 2020)

“If scrap is dirty and polluted, the price will be lower. If it is too dirty and polluted, we do not even want it” (Bäckström, 2020)

“There exist a negative circular effect in not separating copper. You both pollutes the iron and simultaneously loses the copper value” (Bäckström, 2020)

“The problem is the plastics. There are mixed plastic types on the same parts and details. It would have been much better if it was uniform plastics and not all these mixed, molded materials. This makes the plastic contaminated and hence not interesting” (Eklund, 2020)

“You require some volume in terms of cars. In order to manage the associated investment, at least 2000 yearly vehicles are required” (Eklund, 2020)

“More uniform materials would be good. Then the machine could separate these materials as well” (Eklund, 2020)

“The problem with the ELVs is that you do not have time to dismantle the materials manually” (Engblom, 2020)

A.2 Measurements

Table A.1: Summary of all identified measurements from section 4

Variable	Value (Unit)	Description	Source
ELV/P-ELV separator	10 years	*A rough separator for vehicle assortment*	(Jensen et al., 2012)
Yearly scrapped vehicles	200k (pcs)	*Roughly the amount of vehicles scrapped yearly in Sweden*	(Sverkman & Rosdahl, 2020)
Yearly Volvo ELVs	30k (pcs)	*Roughly the amount of yearly Volvo ELVs*	(Sverkman & Rosdahl, 2020)
Yearly Volvo P-ELVs	10k (pcs)	*Roughly the amount of yearly Volvo P-ELVs*	(Sverkman & Rosdahl, 2020)
Average ELV weight	1330 (kg)	*Estimated average weight of one ELV*	(Jensen et al., 2012)
Spare parts to repair shop	75 (%)	*The share of spare parts dismantlers sell to repair shops*	(Jensen et al., 2012)
Spare parts to private persons	25 (%)	*The share of spare parts dismantlers sell to private persons*	(Jensen et al., 2012)
ELV recycling target	85 (%)	*The amount of vehicle weight that needs to be recycled*	(Directive 2000/53/EC, 2000)
ELV recovery target	95 (%)	*The amount of vehicle weight that needs to be recycled and recovered*	(Directive 2000/53/EC, 2000)
Volvo P-ELV dismantlers	7	*The main actors managing Volvo P-ELVs in Sweden*	(Wikström, 2020)
Spare parts from ELV	Few	*The general amount of spare parts collected from an ELV*	Several interviewees
Spare parts from P-ELV	Several	*The general amount of spare parts collected from a P-ELV*	Several interviewees
Fe fraction	67.3 (%)	*Percentage of shredded fraction*	(Sverkman & Rosdahl, 2020)

Variable	**Value (Unit)**	**Description**	**Source**
Al fraction	6.1 (%)	*Percentage of shredded fraction*	(Sverkman & Rosdahl, 2020)
Cu fraction	0.7 (%)	*Percentage of shredded fraction*	(Sverkman & Rosdahl, 2020)
Stainless fraction	0.6 (%)	*Percentage of shredded fraction*	(Sverkman & Rosdahl, 2020)
Fines	10.6 (%)	*Percentage of shredded fraction*	(Sverkman & Rosdahl, 2020)
Material recovery fraction	9.9 (%)	*Percentage of shredded fraction*	(Sverkman & Rosdahl, 2020)
Landfill fraction	4.1 (%)	*Percentage of shredded fraction*	(Sverkman & Rosdahl, 2020)
Exported iron scrap	45 (%)	*Share of iron scrap being exported*	(Material Economics, 2017)
Logistic costs for scrap	10-15 (%)	*Share of fraction cost associated with logistics*	(Bäckström, 2020)
Steel reycling rate	90 (%)	*Share of steel being recycled (Sweden)*	(Material Economics, 2017)
P-ELV price	13 (%)	*Average procurement price paid by dismantler*	(Material Economics, 2017)
Combined revenue	290 (Msek)	*Used as the foundation for the top-down approach*	Yearly Reports BEGO
Volvo P-ELVs	10 000 (pcs)	*Yearly amount of P-ELVs (Sweden)*	(Sverkman and Rosdahl, 2020)
Env.Treat. income	700 (sek/pcs)	*Part of the vehicle income, e.g. for catalyst and battery*	(Jensen et al., 2012)
Hulk income	1.3 (sek/kg)	*Part of the vehicle income when sold to a shredder*	(Jensen et al., 2012)
Dismantled weight	20 (%/pcs)	*Weight of an P-ELV removed at dismantling station*	(Sverkman and Rosdahl, 2020)
Env.Treat. weight	12 (%/pcs)	*Weight removed during env.treat.*	(Jensen et al., 2012)
Fe income	+2.5 (sek)	*Income for fraction*	(Jensen et al., 2012)

Variable	Value (Unit)	Description	Source
Al income)	+17.6 (sek)	*Income for fraction*	Bloomberg Terminal
Cu income	+56.7 (sek)	*Income for fraction*	Bloomberg Terminal
Stainless Steel income	+10 (sek)	*Income for fraction*	(Jensen et al., 2012)
Heavy Metal Mix income	*N/A*	*Not able to find income for fraction*	-
Fines income	-0.4 (sek)	*Income for fraction*	(Jensen et al., 2012)
Material Recovery income	-0.9 (sek)	*Income for fraction*	(Jensen et al., 2012)
Landfill income	*N/A*	*Not able to find income for fraction*	-
Car fraction income	3900 (sek)	*Average shredder income for car fractions*	(Jensen et al., 2012)
Labour cost for dismantlers	36 (%)	*Average share of total cost for BEGOs*	Yearly Reports
Dismantling cost for dismantlers	>50 (%)	*Part of labour cost related to dismantling*	(Wikström, 2020)
DfD improvement	55 (%)	*Potential outcome of DfD implementation*	(Soh, Ong, and Nee, 2014)
Additional Cu mech.dism.	11.88 (kg)	*Net amount of extra copper dismantled through machinery*	(Eklund, 2020)
Additional Al mech.dism.	105 (kg)	*Net amount of extra aluminium dismantled through machinery*	(Eklund, 2020)
Dismantling labour cost	600 (sek/h)	*Cost of one operator per hour*	(Jensen et al., 2012)
Operator time mech. dism.	15 (min)	*Net amount of extra time required to use the machine*	(Eklund, 2020)