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Profitable Remanufacturing Processes in Small and Medium Sized Companies: A Case Study

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PROFITABLE REMANUFACTURING PROCESSES IN SMALL
AND MEDIUM SIZED COMPANIES: A CASE STUDY

BY

STEFAN FERTMANN

A THESIS SUBMITTED IN PARTIAL FULFILLMENT OF THE
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ABSTRACT

Challenges like scarce resources and the threat of climate change will make it harder to satisfy the global demand for industrial goods in the future. The urgency of shifting from the classic way of industrial production to a more sustainable one drives companies to consider remanufacturing activities as a raw material source and business opportunity.

This study was conducted to investigate the profitability of remanufacturing processes in small and medium sized companies, since large corporations are leaping ahead in this field. This problem is approached with a literature review, in order to give the reader insight into life cycle thinking and remanufacturing processes. Then, a case study is conducted in the warranty returns department of a medium sized company.

Different scenarios were calculated to show the benefits and difficulties of conducting remanufacturing operations.

Through this example, this study shows that repairing used products can also be beneficial and profitable for smaller companies. It saves costs for raw material and is more environmentally friendly.

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TABLE OF ABBREVIATIONS

BRR	Beyond reasonable repair
CSR	Customer service representative
C/T	Cycle time
C/O	Changeover time
DFR	Design for remanufacturing
ELSEM	End of live scenario evolution method
EOL	End-of-life
EOT	Element in time
EPEI	Every part every interval
FRW	Free replacement warranty
PRW	Pro-rata warranty
LCA	Life cycle analysis
LCE	Life cycle engineering
LCI	Life cycle inventory analysis
LCIA	Life cycle impact assessment
MGE	Modular grouping explorer
MGNT	Management
NRFRW	Non-renewing free repair warranty
NRFRWCR	Non-renewing free repair warranty with Canada replacements
NRFRWNE	Non-renewing free replacement without evaluation

NRFRWNR	Non-renewing free replacement warranty without repairs
OEM	Original equipment manufacturer
PO	Purchase order
PPC	Production planning and control
PURE	Product upgradability and reusability elevator
Repro ²	Remanufacturing product profiles
RGA	Return goods authorization
VSM	Value stream map / value stream mapping

1 INTRODUCTION

Each year, millions of new products are released by firms to satisfy the demand for consumer goods of human societies. The rapid multiplication of the earth's population and the constantly accelerating advances in modern technologies are boosting this demand. This development causes an increase in resource and energy consumption in connection with rapidly rising emissions, wastes and environmental pollution (Gehin, Zwolinski, & Brissaud, 2008).

Facing serious predicted consequences of human behavior, several developed countries like the United States, Japan and the European Union introduced legislation to encourage awareness of manufacturers to improve their products' environmental performance. The growing demand for sustainably manufactured products is another propellant for corporations to establish ecologically and economically viable ways of manufacturing and distribution. End-of-life strategies which conserve the added value of returned products play an important role in closed loop supply chains (Bhattacharya & Van Wassenhove, 2004).

Over the last few decades, environmental regulations, the rising awareness of resource shortage and economic viability have pushed manufacturers to investigate appropriate strategies of production and supply. Cradle to grave resource management, which was commonly known in the 1980s, refers to the proper disposal of products. Modern environmental resource management closes the supply chain loop and extends it to a cradle to cradle concept (Sameer & Velora, 2008). This concept was introduced by Baumgart and McDonough in their book *Cradle to Cradle: Remaking The Way We Make Things* (Baumgart & McDonough, 2002) as a vision of effectiveness in life cycle

management that basically says that used products are not disposed when they are not needed by the consumer anymore, but brought back to the supply chain as a resource (Toxopeus, de Koeijer, & Meij, 2015)

While some companies, usually global players with a wide spread retailer network and high production volume, manage to develop profitable remanufacturing processes and product recovery strategies, small and medium sized companies struggle to reach adequate economies of scale and achieve operational excellence (Golinska-Dawson & Nowak, 2014).

Remanufacturing as a method for resource procurement is not a new approach. It has been practiced since the beginning of industrialization, especially during times of scarce resources and high demand (APRA, 2015). Today other factors, like reduction of waste and increased sustainability as a competitive advantage to decrease the environmental impact of products, become drivers for growing interest in remanufacturing processes. This is indicated by a constantly growing number of papers published each year with remanufacturing related titles.

1.1 Statement of the Problem

The aim of this thesis is to develop processes and set criteria to facilitate profitable and sustainable remanufacturing processes, shown through a case study in cooperation with an industrial construction equipment manufacturer. The focus is on small and medium sized companies, as remanufacturing is less common for them compared to global enterprises.

The scope of this research will include remanufacturing in general, existing end-of-life strategies and measures to facilitate the technical feasibility of remanufacturing products or recycling materials. It also includes investigating levers to enhance the profitability of these activities.

Since the profitability of remanufacturing processes is heavily dependent on factors that vary from one company to another, it is not the declared goal of this paper to result in a generally applicable principle or model. Nevertheless, the findings and methodology may be used as a guideline to support the development of remanufacturing processes in businesses operating under different circumstances than the here examined manufacturer.

1.2 Overview

Chapter one introduces the reader to the subject of this study, especially to its relevance in the current economic, environmental and academic reality. It also gives a short introduction to every subsequent chapter. The second chapter is a literature review of research and deals with life cycle thinking and the relevant remanufacturing theory, processes and terminology. This chapter also explains why remanufacturing will be an important strategy for manufacturers to run a profitable business in the future. To provide a theoretical background for the conducted case study later in this part, the concept of warranty is explained. The same purpose has the introduction to the value stream method, which is applied during this study. The third chapter deals with the employed methods and data collection. Their theoretical background is explained and how they are applied during this study. This study's findings are shown in chapter four.

First, the results of the historic data analysis are presented and discussed. Different warranty policies are introduced and compared to each other subsequently. Finally, the value stream map approach is used to improve a current state process. Chapter five consists of a short conclusion that highlights the essence of every preceding chapter with a focus on the study's results in particular. Figure 1 displays the two underlying parts of this study, the theoretical part, the literature review and then the conducted case study.

Figure 1: Structure of this study

2 LITERATURE REVIEW

This chapter shall introduce the reader to Life-cycle oriented methods of assessing a product's environmental impacts and concepts of material and part acquisition. It shall also give an overview on typical operations that are conducted on recovered products. These operations or strategies include remanufacturing as a certain degree of disassembly and manufacturing effort compared to other end-of-life strategies. Nevertheless, remanufacturing is also used as a generic term for the activity of collecting products from the market and reutilizing them (APRA, 2015).

2.1 Sustainable development

Since manufacturing contributes a significant share to the global resource consumption and climate-affecting emissions, industry has to shift from the current style of economic growth to a more sustainable one. To enable sustainable growth in the future, companies need to account for the three “Ps”, the three underlying requirements of sustainable development:

- People: social development
- Planet: environmental protection
- Profit: economic development

These three “Ps” mark interdependent goals which cannot be achieved independently. Hence, as companies are classically trying to maximize their profit, they have to adjust their product's impact on people and planet in the future to sustain a profitable growth (Fisk, 2010).

Hopwood, et al.(2005) found that defenders of the current, unsustainable style of development trade economic growth against social inequality and damage to the environment. The authors stress that the discourse about sustainable development is not given the appropriate attention in media and society. In most of the world, it is not on the policy agenda, but the increasing difficulties with the core challenges, the environment and equity, will force it into the focus in the future.

2.2 Life cycle engineering

Herrmann et al. (2014) published an article about life cycle engineering and sustainable engineering in the Journal of Industrial Ecology, which generally deals with research in environmentally friendly design, production, logistics and management. They point out that sustainable manufacturing plays an important role in life cycle engineering, which is referred to as “... *the art of designing the product life cycle through choices about product concept, structure, materials and processes...*” (Herrmann, et al. 2014). The authors conclude from their literature review that manufacturing contributes a significant amount to the energy consumption and emissions in a product’s life cycle. These environmentally negative effects can be reduced through improved processes in manufacturing as well as the assessment of the energy consumption of involved machines. They also name the reduction of manufacturing effort through appropriate end of life strategies (EOL-strategies), which have high environmental benefits (Herrmann, et al. 2014).

Tan, et al. (2014) highlight the role of the Chinese manufacturing industry and market in remanufacturing, since China has emerged as one of the largest players in

manufacturing. However, the Chinese remanufacturing community is dealing with problems like short innovation cycles of electronic products, inadequate regulation systems and a lack of consumer acceptance for remanufactured products.

In order to reduce the manufacturing industry's negative impact on the environment and eventually eliminate or invert it into a positive impact, life cycle engineering (LCE) is used as a method to plan and design product life cycles. LCE considers the whole product life cycle beginning with the design phase and focuses on reducing the environmental impact of material extraction over production and usage to end-of-life strategy. This approach is a measure to shift manufacturing practice from unsustainable resource consumption, mass production and mass disposal to a greener and more future oriented way of production (Umeda, et al., 2012).

2.2.1 Life cycle assessment

Several other methods are closely related or subordinated to LCE. This includes life cycle assessment (LCA) and life cycle design (LCD). LCA refers to the assessment of the environmental impact of a product by compiling and evaluating inputs and outputs over the whole life cycle. This helps to identify opportunities to reduce the environmental impact of product manufacturing and consumption at certain stages in a product's life cycle. It also raises awareness of resource and energy consumption in consumers and producers. This awareness is the first step to improve the environmental performance of products and represents a new marketing opportunity, as greener products are important to a growing environmentally aware consumer group. ISO 14044

details requirements for conducting an LCA study. It shows up the principles, phases, methods and key features for practitioners (Figure 2).

Figure 2: Phases of a life cycle analysis (ISO14040:2006(E))

Phase one of an LCA is completely preparative and serves as the operational frame of the study. It consists of the goal and scope definition. The study's goals state the reasons for the study, who will eventually have access to it and if the application is intended. The scope defines the product or system that is subject to the study, the system boundaries and what data needs to be collected. A life cycle inventory analysis (LCI) is phase two of an LCA. The goal of this analysis is collecting and calculating data of in- and outgoing energy and material flows. For example, this can be ingoing raw material and outgoing gas or waste water emissions. After the creation of a sufficient data base, data needs to be validated and related to functional units and unit processes. The subsequently following evaluation phase consists of a life cycle impact assessment (LCIA). During an LCIA, a number of steps are carried out with the goal to assess the significance of environmental impacts. This is done by connecting the earlier collected and validated inventory data from phase two with environmental impact categories and

indicators. Values and subjectivity of these indicators and categories need to be made transparent for a critical review and, as well as the methodology, depend on the LCIA's goal and scope. The results and findings from the preceding phases are considered in the interpretation phase. The intended outcome of this phase is a conclusion that is covering the goals and scope and providing recommendations to decision makers for measures to improve a product's or a process's environmental performance. All previously described phases of an LCA are iterative processes that influence each other, so adjustments need to be done continuously. For example, findings from the interpretation phase might indicate that the study's scope needs to be redefined, which has an impact on phase two and so on.

An integral part of an LCA is a final critical review and an adequate report. Minimal requirements for this report is that it contains a description of the analyzed data, employed methods and assumptions, a conclusion and limitations.

Since the defined goals and scope limit the study to a certain extent, there is the possibility of not capturing all environmental impacts of a product life cycle. Another source for missing or misinterpreting environmental impacts might be the use of an insufficient model, poorly set system boundaries or unprecise impact categories and indicators (ISO14040:2006(E)).

2.2.2 Life cycle design

Life cycle design is a concept of planning a product's life cycle ahead to minimize its environmental impact and to maximize consumers and producers benefit. To do so, Luger and Herrmann state that product responsibility needs to be extended to a product's

end of life (Luger and Herrmann 2010). This pushes manufacturers to come up with plans for their products' whole life cycles, including end of life strategies like remanufacturing. Ishii found that this is most effectively done in the early layout phase of a product, because many decisions are uncertain and the design can still be adjusted (Ishii, 1995).

The complexity of product life cycles dramatically increases as soon as different life cycle phases need to be integrated. Herrmann, et al. (2007), describe this case with the example of intersecting life cycles of a machine tool and the machine tool's product. While the machine tool's life cycle is in the usage phase, its product is still in the manufacturing phase. Therefore, the machine tool manufacturer needs to consider the product's life cycle and possible changes to it. The machine tool user, however, needs to account for changes in their machine tool's life cycle that are due to changes that they made to their own product's design. In other words, the machine tool might not be able to produce a product anymore, if it is designed differently. This correlation becomes a complicated system, when not only one life cycle intersection, but many primary and secondary products with multiple intersections are considered (Herrmann, et al. 2007).

Life cycle oriented methods are used to assess a product's environmental impact and environmentally conscious manufacturers use them to improve their products and design new, environmentally friendly life cycles.

2.3 Remanufacturing – a life cycle oriented production method

The following section introduces the reader to the concept of remanufacturing. As a life cycle oriented production method, it starts with the treatment of the collected cores. Different ways of core circulation and processing are described. Ecologic dimensions and the role of labor in remanufacturing are also made subject to this section.

2.3.1 EOL Treatments in remanufacturing

When a product reaches the end of its useful live, it needs to be collected and brought back to the manufacturer. This product collection process is followed by an end-of-life or end-of-use treatment, where the used product is either reused or disassembled to a certain degree and partly or completely brought back into the manufacturing process.

The recirculation of components, parts or materials into different stages of the manufacturing process is shown in Figure 3. This figure also shows that disposal is the last option which is only chosen if the part cannot be reused in the primary or secondary market with or without any treatment and if the materials that it consists of cannot be recycled. At this point remanufacturing is used as a generic term for reusing, refurbishing, remanufacturing and recycling.

Figure 3: Various reverse logistics product paths (Sameer & Velora, 2008)

The above displayed end-of-life strategies can be defined as follows (Lindahl, Sundin, Östlin, & Björkman, 2006):

- Reuse:** The process of taking usable parts from returned products to reuse them as components for newly manufactured products. These parts might have reached a different level of fatigue so service intervals can differ from new products.
- Refurbishment:** Restoring and cleaning of components so they can be sold again.
- Remanufacture:** Disassembly, inspecting, cleaning and repairing the returned parts so they are equal to new products. This also includes the replacement of wear parts and upgrading or modernization without scrapping the old product.
- Recycling:** Parts are disassembled, sorted by material, shredded or melted to be a raw material for new products. This means that the part loses its shape and needs to be run through an energy intensive process again.

The correct terminology is important here. Recycling, for example, should not be mistaken with reuse, due to the significantly different level of end-of-life treatment with different costs and ecological and economic impact (Lindahl, et al. 2006).

The hierarchy of EOL treatments indicates in which order they should be picked to achieve the most beneficial outcome. The values contained in a product, added by previously undertaken treatments in manufacturing and assembly, shall be preserved to the greatest extent possible. This means that the loss of added value and increasing effort in the end-of-life treatment are greater in recycling compared to reusing (Diener, 2015).

In the automotive industry, there is a considerable debate about the two terms *remanufacturing* and *rebuilding* and which of these words describes more accurately the process of recovering, treating and reusing parts that come back from the market. In conclusion, it can be said that these two terms can be used interchangeably, which provides some potential for confusion (APRA, 2015). Only the word *remanufacturing* will be used subsequently in this thesis, since it is most widely spread and has become a synonym for all kinds of end-of-life treatments, excluding disposal and material recycling.

2.3.2 Improving remanufacturability during the design stage

The following section introduces the concept of design for remanufacturing (DFR), which aims at utilizing the initial design phase of a product to reduce the complexity of subsequent remanufacturing operations. The required effort for remanufacturing

operations can be reduced significantly, if remanufacturing operations are considered by design engineers during the early phases of product design.

Beginning with the core collection and subsequent disassembly and reconditioning, the remanufacturing process appears to be a reversed production process. A classic production process is heavily dependent on the design effort that is put into the product before the start of production. Concepts like Design for Assembly (DFA) or Design for Manufacture (DFM) provide principles to facilitate easier, faster, cheaper and more efficient processes and are commonly known under the keyword Design for X (Boothroyd, Dewhurst, & Knight, 2011).

In contrast to increasing the effort in more and more complicated remanufacturing operations, which also increases the energy and material demand, product designers should be convinced to consider a cradle to cradle lifecycle by empowering remanufacturing processes. An effective way to reach this goal is developing products with higher remanufacturability (Hatcher, Ijomah, & Windmill, 2011)

Many technical barriers restraining the remanufacturing process are related to the design of the product. Steps like disassembly, for example, can be impossible to carry out without causing damage if this kind of end-of-life treatment was not considered during the construction of all parts. Design for manufacturing methods that enhance a one-time assembly progress, can complicate efficient disassembly. Example are snap fits, thermal press fits or rivets. Therefore the concept of design for remanufacturing describes the consideration of an efficient remanufacturing process in the early stage of the initial product design (Hatcher, Ijomah, & Windmill, 2011).

Since there are several definitions of design for remanufacture in the literature, the following two are given as an example, one older and one more recent definition:

- “Product design that facilitates any of the steps involved in remanufacture...”
(Shu & Flowers, 1999)
- “A combination of design processes whereby an item is designed to facilitate remanufacture” (Charter & Gray, 2008)

From these definitions can be extracted that design for remanufacture is the task where the designer of a product enables the remanufacturing process to be as efficient as possible.

While investigating measures to facilitate remanufacturing operations during the design phase, Sundin found a relation between certain steps in remanufacturing and product properties, which are displayed in the RemPro-matrix (Sundin, 2004) shown in Figure 4: RemPro-Matrix (Sundin, 2004, p. 82)

<div> <div>Remanufacturing Step</div> <div>Product Property</div> </div>	Inspection	Cleaning	Disassembly	Storage	Reprocess	Reassembly	Testing
Ease of Identification	X		X	X			X
Ease of Verification	X						
Ease of Access	X	X	X		X		X
Ease of Handling			X	X	X	X	
Ease of Separation			X		X		
Ease of Securing						X	
Ease of Alignment						X	
Ease of Stacking				X			
Wear Resistance		X	X		X	X	

Figure 4: RemPro-Matrix (Sundin, 2004, p. 82)

Through three case studies Sundin found four properties to be the most significant and most frequently important measures for an efficient remanufacturing process. These are:

- Ease of access
- Ease of identification
- Wear resistance
- Ease of handling

Notice in Figure 4 that some of these properties influence the remanufacturing process in several stages. Sundin (2004) also suggests that companies who are starting a remanufacturing business, should use his RemPro-Matrix to design their products according to the design for remanufacturing principle. He also points out that the matrix supports companies in taking crucial steps in preparation of their remanufacturing lines. He adds restrictively that the RemPro-matrix was not already proved as a design tool at that time. According to Sundin, the current research (2011) remains mostly in the academic realm, and proof of application in the industry is hard to find. He assumes that original equipment manufacturers (OEMs) prefer to conduct their own research, not providing their findings, methods and strategies publicly for competitive reasons (Sundin, 2004).

The following sections provide a short description of some methods and tools that are used in the Design for Remanufacture concept reviewed in the literature by Fegade, Shrivatsave, & Kale (2015).

2.3.2.1 Modular grouping explorer (MGE) tool

According to Tchertchian, Millet and Pialot (2013), most products on the market today do not consist of defined modules, from the end-of-life standpoint. In order to assign modules of a product to a certain end-of-life treatment, the design process consists of three basic principles of the Modular Grouping Explorer tool, or MGE-Tool: Questioning module frontiers, redefining the remanufacturable or recyclable nature of initial modules and grouping of modules by calculating their affinity. The advantage is the questioning of the full product architecture as well as its modules and components. MGE guides and supports the design team during the exploratory process of developing a new product but cannot be seen as a systematic tool (Tchertchian, Millet, & Pialot, 2013).

2.3.2.2 Design process for taken-back part reuse

This concept provides a guideline for designers when considering the utilization of recovered parts in the design phase of new products. It especially highlights the use of returned products that had not been designed for more than one lifecycle. Dividing the process into conceptual and detailed design with sub items like functional and structural design, this guideline goes through a classic design process from the perspective of reducing the amount of new parts as well as the amount of scrap (Wu and Kimura 2007).

2.3.2.3 Design for life cycle profit simultaneously considering manufacturing and remanufacturing

Kwak and Kim (2015) developed a decision support model based on mixed-integer nonlinear programming to maximize the total life cycle profit, generated by the initial

manufacturing and subsequent remanufacturing processes. This mathematical model helps manufacturers find an optimal product design to achieve a green and profitable business by considering trends in product obsolescence and customer preferences. Therefore, this model is considered to be a design for remanufacture tool as well as a design for life cycle profit tool (Kwak & Kim, 2015).

2.3.2.4 Product upgradability and reusability elevator (PURE)

The approach of Product Upgradability and Reusability Elevator (PURE) is a mathematical model that helps to determine the upgradability and reusability of products to extend their service life. With a focus on the essential technical characteristics, remanufacturing potential of a product is investigated on three different levels of product representation: the engineering metrics, the component and the structural level. Even though the model yields reasonable results, a disadvantage is that cost factors are not being directly included in the model and evaluation (Xing, Belusko, Luong, & Abhary, 2007).

2.3.2.5 Design process model for sustainable remanufactured products

The tool Repro² (REManufacturing PROduct PROfiles) was developed to be integrated into daily design work, so that it enables designers to evaluate the environmental impacts of their products and offers information in order to reach a successful remanufacturing situation. The tool uses remanufacturing profiles of products to assess different industrial situations for profitable remanufacturing cases and eleven different profiles were characterized to achieve this goal.

Designers can use the Repro² tool to determine which kind of profile their product can be sorted into and draw conclusions about the remanufacturability from this (Gehin, Zwolinski, & Brissaud, 2008).

2.3.2.6 EOL scenario evolution method (ELSEM)

The End of Life Scenario Method (ELSEM) was developed to help design engineers make decisions about EOL options so they are environmentally friendly and economically beneficial. Remery et al. (2012) introduce ELSEM in their paper “A new method for evaluating the best product end-of-life strategy during the early design phase” as a simple to use and quick method which also provides the option of flexibly weighting EOL options differently, if the designer or company has specific environmental or economic intentions. However, the precise knowledge of these options is not a prerequisite for using this tool. Another advantage is that an individual EOL option can be considered for each module of a product (Remery, Mascle, & Agard, 2012)

2.3.3 Typical procedure of a remanufacturing process

Barquet et al. (2013) defined the following stages as a part of the remanufacturing operation after the core has arrived at the manufacturer’s plant:

1. Total product disassembly to have access to every single part. This is a labor and time intensive process due to its complexity.
2. Cleaning of disassembled parts. This process varies depending on the material. Parts undergo chemical or heat treatment as well as mechanical action.

3. In the subsequently carried out inspection, parts are classified by their condition.
This means that a decision is made on if and how the cores can be used for the production of new products. Some parts might just be assembled again, others might need to be repaired, recycled or even disposed.
4. Once the cores are sorted according to their condition they run through a reconditioning process (reprocessing) to bring them back to a like-new quality.
This includes that some components might need to be replaced with new ones.
5. After the quality of the reprocessed parts is checked, they can be reassembled.
A final test is employed to ensure that the remanufactured products are equal to new ones in terms of characteristics, functionality and quality.

The order of the activities described above might differ according to the characteristics of the remanufactured product. Nevertheless, all of them are usually carried out. Figure 5 gives an impression of how these stages line up to form the remanufacturing line in a plant.

Figure 5: Stages of the remanufacturing process

2.3.4 Workforce in the remanufacturing operation

The operation of a remanufacturing system does not require higher qualified employees, but they should be familiar with the whole remanufacturing system so that they can function professionally with varying quality and quantity at each stage of the process from acquisition of cores to the assembly and sale of the remanufactured product. In remanufacturing, it is important to have skilled and unskilled employees, to combine their experience and their ability to think “outside the box” respectively. Higher qualified employees should be responsible for tasks like inspection and testing, which require higher skills compared to cleaning, disassembly or assembly (Barquet, Rozenfeld, & Forcellini, 2013).

2.3.5 Integrating remanufacturing into a hybrid production

The current literature dealing with hybrid manufacturing and remanufacturing production mostly focusses on various optimization models. This section rather focusses on the qualitative research than on the description of numerous mathematical models.

A Hybrid production is characterized by some differences compared to a classic production that create problems for traditional production planning and control (PPC) methods (Guide, 2000). The seven main problems are listed in Table 1. This table also shows a short description of the respective characteristics and effects.

More recently, Lage and Filho (2015) conducted four case studies in the automotive sector. They identified another difficulty that has not been investigated in previously published literature. Lage and Filho found that OEMs have to cope with a lack of cores due to a high demand of manufactured goods and low returns. The authors also conclude

that higher volume in manufacturing causes a reduction of the existing remanufacturing labor pool. They suggest this phenomenon to be a subject for future research. Contrary to the authors' classification of their case study's yield as an eighth different characteristic, it can be concluded that the manufacturers in the examined case studies are struggling to balance demand and recovered products, which was classified as a difference in characteristics by Guide (2000).

Besides discussing the seven complicating characteristics, Guide (2000) conducted a survey in the remanufacturing industry. His research yielded that the majority (60%) of the interviewed remanufacturing executives state that the greatest threat to industry growth is the pressure to shorten lead times. 50% of the study's participants identified a lack of cores, while products being designed for disposal is another threat that was named by 34% of interviewees.

Aras, Verter und Boyaci (2006) developed two models in order to determine under which circumstances remanufacturing or manufacturing should be prioritized in a hybrid system. The numerical experiments yielded a critical return ratio, which is the threshold at which the priority changes from manufacturing to remanufacturing. If the rate of returning cores is below this threshold, it is more beneficial to manufacture new products, and if it is above, the priority should go to remanufacturing. The authors emphasize that this result is only valid for hybrid systems in which the cost of remanufacturing is lower than the cost of manufacturing. Another restriction is that the models did not include the costs of disposal, which can be positive or negative. Therefore these costs were set to zero.

Problem	Characteristics and effects
Uncertainty in amount and timing of returned cores	Uncertain timing of a products EOL cause varying rates of turned in products. A great influence has the technological progress and precise forecasts are crucial for planning purposes.
Balancing demand and returned products	Function of product's expected life and rate of technical advance. Balance can be maintained by sophisticated inventory management (MGNT) and additional cooperation between other functional areas.
Disassembly of products	Expensive process, since it is labor intensive. High impact on PPC systems, requires coordination with reassembly to avoid high inventory.
Uncertainty about core quality and recovery rate	Remanufacturability of returned products varies and yields different, usually by simple averages predicted rates of remanufacturable parts.
Requirement of a reverse logistics supply chain	Complex system of core acquisition. Requires a number of logistic facilities and incentives for turning cores in.
Materials matching restrictions	Customer owns turned in product and requests it back after processing. Complicates resource planning, shop floor control and materials MGNT.
High variability of processing times and stochastic routings	Processing time is a function of core condition. Variability makes resource planning, scheduling, shop floor control, materials MGNT and lot sizing more complex.

Table 1: Characteristics of hybrid manufacturing (Guide, 2000)

2.3.6 Ecological dimensions of remanufacturing

Drivers for firms to engage in reverse logistics including end-of-life strategies are not only the reduction of the ecological footprint of each product but also economic advantages. According to Allwood et al. (2011), the approach of remanufacturing can

result in 30% - 90% reduction in energy and material consumption, compared to newly manufactured products. Even though it might not be the main driver for manufacturers, another effect is the positive environmental impact, which can also be beneficial for the corporate image of a firm.

2.3.7 Remanufacturing supply chains

Over the last few decades environmental regulations and the rising awareness of resource shortage and economic viability have pushed manufacturers to investigate appropriate strategies of production and supply. Cradle to grave resource management, which was commonly known in the 1980s, refers to the proper disposal of products. Modern environment resource management closes the supply chain loop and extends it to a cradle to cradle concept (Sameer & Velora, 2008). Figure 6 shows a schematic representation of a cradle to grave and a cradle to cradle supply chain to demonstrate the different material flow after the useful life of a product.

Figure 6 Cradle to grave (top) and Cradle to Cradle (bottom) life cycles

The cradle to cradle concept was introduced by Baumgart and McDonough in their book *Cradle to Cradle: Remaking the Way We Make Things* (Baumgart & McDonough, 2002) as a vision on effectiveness in life cycle management that contains three main principles:

- Waste equals food. Referring to metabolism cycles, waste should be seen as a resource for new product lifecycles.
- Usage of sustainable energy. Only renewable energy sources should be used in a cradle to cradle product lifecycle. This is based on the assumption that sustainable energy is widely available without restrictions.
- Celebrate diversity. Biodiversity, cultural and conceptual diversity are improving relationships, creativity and innovation. Homogeneity and concentrating on single criterions might cause instability and lead to imbalance.

This implies that used products are not disposed when they are not needed by the consumer anymore, but brought back to the supply chain as a resource (Toxopeus, de Koeijer, & Meij, 2015).

Besides economic drivers, regulatory pressure towards recycling, reuse or remanufacturing instead of mere disposal exists in industrial countries like the U.S., Japan and European countries. Europe in particular puts “take-back” responsibility on firms, so in order to take part in the European marketplace, companies are forced to put plans for product returns in place. This shall prevent environmentally hazardous and

unhealthy materials from being disposed of in landfills or contaminating natural resources (Sameer & Velora, 2008).

The following portion of this paper will give an overview of different reverse logistics systems, consisting of a product collection concept, followed by an end-of-life process.

As a crucial part of the closed loop supply chain, the right product recovery strategy plays an important role. There are three main collection methods for used products.

1. The manufacturer collects directly from the consumer. Canon, for example, uses prepaid mail boxes to return products, and the retailer is not involved in this process.
2. The retailer collects from the consumer and the manufacturer buys-back from the retailer. This is demonstrated by the example of Kodak buying back single-use cameras from retailers, where consumers brought them to develop films.
3. A third party collects from consumers and sells them back to manufacturers. This is practiced with cars or refrigerators.

Due to the simpler transfer price schemes, the last two methods allow the manufacturer to coordinate the supply chain easier (Sameer & Velora, 2008).

A manufacturer's decision to select a certain product recovery policy is influenced by several factors. Most important are the overall cost for recovery. Other factors depend on the market, the product, on competition and on the availability of third parties acting as brokers in reverse logistics, as well as regulations and laws. The latter is most likely the case if the third party can work with several manufacturers and occurs in

economies of scale. The fact that the third parties can decide the price per used product is characteristic for this collection method.

The retailer collection method provides the advantage that retailers also engage in the promotion and collection of used products. It also means that the ownership of returning products rests with the retailer and in order to pick up the collected products, manufacturers have to pay a transfer price per product.

The first presented method is advantageous for the manufacturer, because he can decide the wholesale price and product return rate independently. (Savaskan, Bhattacharya, & Van Wassenhove, 2004).

2.4 Lean and green

This section introduces the reader to the origin of lean thinking and deals with the correlation between green manufacturing and lean manufacturing.

After world war two, the Japanese industry was facing drastic resource scarceness and was forced to improve its productivity to stay competitive. In order to produce profitably under adverse conditions, the *Toyota Production System* was developed. This system focusses on continuous improvement through the commitment of all stakeholders and through the elimination of waste. *Lean thinking* is a term that was developed by Womack and Jones (2010) and it is derived from the Toyota Production System and can be considered to be a modern, American version of it. The essential objective, the elimination of *Muda*, which means *waste* in Japanese, is to reduce work content that is not productive. The Toyota Production System and Lean Thinking both identify the following seven types of Muda:

- Defects: Effort wasted on products that do not generate revenue
- Overproduction: Things that are made but not demanded by customers
- Inventories: Waiting units that are backlogging production flow
- Over-processing: Carrying out unnecessary manufacturing operations
- Human motion: Unnecessary motion of employees
- Transportation and handling: Moving products or inventory around
- Waiting: Stopped or idling processes and inventories

These types of waste are reducing productivity and complicating manufacturing and assembly processes. The goal of the *lean thinking* approach is to maximize the operational performance of a production line or whole supply chain.

Green manufacturing is a term that describes environmentally conscious production practices with the objective of reducing pollution and resource consumption.

Dhingra, Kress and Upreti (2014) found in their literature review that the avoidance of waste, as it is advocated in lean production methods, applies to green manufacturing principles. Thus, the authors' research question is if lean production is automatically a green, or environmentally friendlier, production.

The authors stress that lean and green manufacturing overlap in the perception of waste and the usage of resources. While lean thinking focusses on the reduction of waste and maximizing productivity in order to realize a high output with the lowest possible input, green initiatives also consider eco-product design, design for remanufacturing and the reduction of toxic materials. Green manufacturing also includes life-cycle assessments to understand a product's environmental impact. Facing scarce resources

and increasing customer awareness of a products environmental impact, manufacturers realized that advancing from *lean* to *green* is a natural progression. Implementing cleaner production methods promises monetary savings and, thanks elimination of toxic materials, improves staff health and lowers risk of product safety recalls. Lean manufacturers are likely to benefit from their experience in reducing waste and their sensitized employees when advancing from a lean production to a green production. A positive consequence of manufacturers being more environmentally conscious is a possible *domino effect* on the whole supply chain.

Dhingra, Kress and Upreti (2014) conclude that experts in the area of lean need to think of environmental benefits not only as a positive side effect, but as an intended benefit. At the same time, green initiatives should incorporate more economic points of view, in order to increase the overlap of these two areas. The authors finally recommend companies to apply lean and green methodologies in an integrated manner, overlooked by a *Sustainable Champion*.

2.5 Theoretical background of a value stream analysis

The value stream approach on a manufacturing process aims to make a production leaner. As described in the book “*Lean thinking: banish waste and create wealth in your corporation*” by Womack and Jones (2010), this means that non-value creating activities are eliminated. This concept was originally developed as the Toyota Production System by Taiichi Ohno, which is why many of the terms which are used

are in Japanese. Most importantly, the authors urge manufacturers to think of processes as a flow and not discrete production processes, since it is the only way to implement lean systems instead of isolated process improvements (Womack & Jones, 2010).

As the title of Roth and Shook's book "*Learning to See*" (2003) suggests, a Value Stream Map (VSM) is a tool that helps look at processes in the right way, in order to determine the means to improve them. It is carried out by following a product's path backwards through its production and drawing a visual map with pencil and paper (Roth & Shook, 2003).

Roth and Shook (2003) define a value stream as the sum of all the activities that are required to produce a product and deliver it to the customer. Subsequently in this study, only the production flow from raw material or core to the customer will be considered. Actions in this value stream can be categorized in two different ways:

- Value added
- Non-value added

Value added actions are those that actually create value for the customer, and they are the essential part of every production. Non-value added actions need to be seen critically. They are not beneficial to the customer, and therefore they need to be minimized. Since not all necessary steps in manufacturing are actually value adding, clamping a work piece for example, non-value adding activities cannot be eliminated completely. Therefore it is desired to identify muda, the non-value creating activities that are not necessary, and eliminate them. The question "*Would a customer be willing to pay for this?*" helps to identify non-value adding activities. A negative answer indicates that the necessity of the observed process needs to be investigated.

While mapping a value stream, it is important to notice that there are two different kinds of flows that contribute to the production of a good. The first one that comes to mind is the material flow, because it is more visible. The less obvious, but just as significant flow is the information flow, which is controlling every process. A well designed information flow controls every process in a way it serves its customer, the next process down the line. This ensures that a process makes only what the subsequent process needs and when it needs it (Roth and Shook 2003).

When measuring processes for a VSM, different times can be considered. The cycle time (C/T) is the time from one unit leaving the process until the following part leaves the process, measured in seconds. Changeover time (C/O) is the time that is needed to switch from producing one product type to another, also in seconds. The available working time per shift is calculated by the length of the shift minus break, cleanup and meeting times in seconds. Another important information is the machine uptime. EPEI time stands for every part every interval, which is the time to produce one batch of every product. Hence the EPEI time is the sum of each products C/T multiplied with the batch size plus C/O times.

Figure 7: Phases of the value stream approach

The value stream approach consists of two phases, the analysis phase and the design phase. Figure 7 shows how they are interrelated. First, one product family needs to be selected. This is a means to reduce the value stream map's complexity. Then the current state is analyzed. Phase two starts with the design of an improved process chain by using the collected data and findings from the analysis phase. Eventually, adjustments are made to transform the current state value stream into the future state value stream. This transformation is a continuous improvement process, hence adjustments are continuously analyzed and checked for their effectiveness

2.5.1 Current state mapping

While drawing a value stream map, typically by hand with pencil and paper, standardized symbols are used. This guarantees that any reader, who is familiar with Value Stream Analysis (VSA) methodology, can easily understand the visualized process chain. The most frequently used and basic symbols are presented and explained subsequently in this chapter.

Figure 8: Icons for drawing a current state VSM (Roth and Shook 2003)

Figure 8 shows icons that are commonly necessary to draw a current state value stream map. Symbols for a supplier's or customer's factory stand for the origin or destination of deliveries are shown, drawn as arrows with a schematic image of the transportation vehicle on it. Manufacturing processes are recorded as boxes with the process name and an operator icon in it. It also shows the number of operators next to the icon. Data boxes below factory or process icons provide space for related process data as listed below:

- C/T (Cycle time)
- C/O (changeover time)
- Uptime (on-demand machine uptime)
- EPEI (production batch sizes)
- Number of product variations
- Working times (minus breaks, meetings, cleanup time)

If finished goods from one process are pushed to another process, the mapping icon that is used is the striped arrow. Due to the characteristics of a push-material flow, inventory might build up. Existing inventory is represented as a triangle on the striped arrow with the number of pieces and the inventory range noted below. The previously described icons are only sufficient to map a physical value stream. The flow of information also needs to be displayed in the value stream map. Information flows are divided into normal information flow and electronic information flow. The former is represented by a narrow lined arrow, the latter by an arrow with a lightning-like waggle. The eyeglass icon is used for complicated scheduling processes, where supervisors have to do scheduling based on their inventory observation. The timeline shows how long a product is processed and how long it is stored as inventory on the shop floor. C/T times are noted on the lower lines, which are below a process box. The upper lines are below the inventory triangles and show the range. The lead time for one unit to go through the shop floor is determined by compiling all times on the timeline. Usually, the process time, noted in the lower box at the timeline's end, is significantly shorter than the lead time, noted in the upper box at the timeline's end. It is desired to reduce the lead time

by shortening changeover and wait times, so the share of process time increases (Roth and Shook 2003).

2.5.2 Future state value stream map

Just like a regular production process, it is desired to design a lean remanufacturing process. A red pencil is used to mark high in-process inventories and other kinds of waste on the current state map. Then ideas to improve the value stream are also drawn on it. Roth and Shook (2003) name seven guidelines to help design a lean value stream, which can be employed after the current state value stream map is completed.

- Guideline No. 1 is producing in takt time. This is the theoretical cycle time of the customer buying a finished product. It is calculated by dividing the available working time per shift by the customer demand rate per shift:

$$Takt\ time = \frac{Available\ working\ time\ per\ shift}{Customer\ demand\ rate\ per\ shift}$$

- Guideline No. 2: Develop batch processes into continuous flow processes. This is an effective means to reduce inventory, because a product is simply passed through from one processes to another without stagnation. Process icons of combined processes in the current state map become one process box in the future state map. Assembly A, Assembly B and Assembly C would become Final Assembly for example.
- Guideline No. 3: Using supermarkets to connect upstream batch processes with continuous flow processes. If a process cannot be included into a

continuous flow, it should be controlled by a pull-system, so it can operate in batch mode and still be linked to the downstream demand.

- Guideline No. 4: Sending customer schedule to pacemaker process only. This pacemaker process sets the pace for all upstream processes. Therefore the pacemaker process needs to be selected carefully. Since the pace can only be set for upstream processes, downstream material transport cannot be executed with a pull-system.
- Guideline No. 5: Level the production of all products over time. Instead of producing large batches, it should be desired to schedule small batches in order to reduce high in-process inventory. The product mix is scheduled at the pacemaker process, so all upstream processes follow automatically.
- Guideline No. 6: Leveling the production volume. This can be done by releasing smaller orders to the pacemaker process regularly instead of large batches less frequently. This smooths the change in production volume so the performed work does not peak as high and fall as low compared to a workflow with large increments of work released at a time. This makes the value stream more predictable and errors can be detected and fixed sooner. A tool for controlling the product mix and leveling volume could be the Heijunka-Box.
- Guideline No. 7: Reduce interval length in EPEI. The interval in EPEI should be shortened continuously, from weeks to days to shifts to hours. The goal for plants that are producing high-running part numbers is to produce at least every part every day.

Figure 9 shows the common icons for drawing pull mechanisms in a future state map. The withdrawal icon is used when a process pulls goods from a supplier process' supermarket. The production Kanban is triggered by a withdrawal from the supermarket and orders the supplier to refill the supermarket with the withdrawn product type. The supermarket symbol is open on the left side, facing the supplier process. It is a visual representation of customer usage. A supermarket on the shop floor should be located close to the supplier process, so it is easily accessible.

Figure 9: VSM future state icons (Roth and Shook 2003)

The withdrawal Kanban stays in a box with the product it is assigned to. When replenishment is needed, the process operator hands it to the material handler, who withdraws another box from the supermarket. The level production mix icon is inserted

into information flow arrows and used as described as in Guideline No. 5. If Kanban are collected to be transported together, the batch Kanban symbol is used. The Kanban post icon is placed where Kanban are collected and stored until they get transported. A triangular signal Kanban indicates that the supermarket contains less than the trigger amount of a certain product type. It is transported from the supermarket to the supplier process and schedules a replenishment batch. A FIFO icon between two processes means that orders are released in the order that they are received at each process. The FIFO lane can only contain a certain number of parts, so when it is full the supplier has to stop until a unit exits the FIFO lane. The sequenced ball symbol can be inserted instead of a supermarket that provides all part numbers. A sequenced pull is when a customer process' order triggers the production of a predetermined number of a certain part number. Short lead times in the supplier process and strict ordering rules for the customer are a requirement for this (Roth and Shook 2003).

2.6 The Concept of warranty

A warranty serves as a liability between the two parties of a purchase contract. It assures that the sold product is as represented in terms of quality and performance. The warranty contract specifies the buyer's claims and the seller's obligations in the event of a failure despite proper operation or unsatisfactory performance. The distinction between a guarantee and a warranty is that a guarantee is the pledge for assurance over something, while a warranty is specifically the guarantee for a purchased product. A warranty is not to be mistaken with a *service contract* or an *extended service contract*. These are optional services of the seller which are billed to the buyer additionally, while a warranty is already included in the purchase price. Another term is *extended warranty*, which is a service contract that prolongs the warranty period for a fee.

Warranties have different advantages for each side of a purchase contract. For the buyer, a warranty is a protection against purchasing a faulty item on the one hand, and a quality indicator on the other hand. The buyer assumes that a product with a longer warranty period is more likely to be reliable than one with a shorter period of coverage. Since warranties make product more attractive and influence purchase decisions, they are of promotional purpose to the seller and can distinguish his product from other manufacturer's products (Blischke and Murthy 1995).

Warranties can be one or two dimensional. A one-dimensional warranty covers failures of the sold product over a certain period, while a two dimensional warranty also provides coverage for another factor that wears the product, for example mileage of a car or a machine's hours of operation. The cost for the manufacturer to service a

warranty depend on the servicing strategy. Iskandar, Murthy and Jack (2005) name two options for companies to rectify a faulty product:

1. Repair
2. Replace

The first option is financially beneficial, since it costs less than a replacement. On the other hand, a repaired unit is more likely to fail in the remaining warranty period than a new one. It is the manufacturer's interest to determine which strategy is less costly for him.

Blischke und Murthy (1995) also name additional options that give the buyer credit for failed units. This could be a *lump-sum rebate*, like a "money back guarantee" or replacements for a lower price than the initial retail price. The authors describe free replacement warranties (FRW) as a common warranty police. A pro-rata warranty (PRW) specifies the amount of credit the buyer receives for a failed unit as a function of its usage or age. This is an attempt to more precisely replace the products current value. A third type is a combination of these policies, an FRP/PRW policy. It covers failed units with a free replacement up to a certain time after purchase. Once this time frame is exceeded, the policy turns into a PRW. Another option for manufacturers when they decide about their warranty policy is if they want to offer a *renewing* warranty. In this case, the warranty period starts from zero after a buyer's warranty claim has proved to be valid and he received a replacement or a repaired product. In contrast to this, a *non-renewing* warranty just covers the remainder of the initial warranty period.

As described earlier, an extended warranty is a service provided by the manufacturer. When deciding to offer such a service, the manufacturer has to consider carefully if the expected increased revenue, due to the attractiveness of an extended warranty, exceeds the higher cost of servicing such a warranty policy. Like a regular warranty, the extended service can be either renewing or non-renewing, including free repairs or replacements and be one or two dimensional. Depending on the type of basic warranty, which is the free, obligatory warranty, the start and end date are defined. In a one-dimensional warranty, the extended time frame starts when the basic warranty expires. A two dimensional warranty, however, can also expire in the event of exceeding the second dimension's limit. In the example of a two dimensional car warranty, covering time and mileage, this could be the mileage limit. When the basic warranty expires, the extended warranty becomes effective. This event might even cause the expiration of an extended warranty within the covered period of time of the basic warranty (Su and Shen 2012).

3 METHODOLOGY

This chapter describes the procedure of the conducted case study at company X. Preliminary, it gives a short overview on the employed methods and goes into detail afterwards. The case study is employed to determine which difficulties companies face today in dealing with warranty returns and to develop insights on remanufacturing with methods to cope with such difficulties. Company X currently aims to understand several problems that it has encountered. First of all, processes for warranty returns need to be analyzed. The present processes are not efficient, indicated by long processing times and high inventories. A key question is, whether it is suitable to repair products in a case of warranty or if this effort outweighs the cost for providing a new product for a small fee. To investigate this problem, data needs to be collected and a number of considerations have to be made. This includes the profitability of processes but also sustainability of production and customer acceptance for remanufactured products. Other considered factors will be the possibility of parts procurement from returned products and an approach to deal with waste and scrapped products or parts. Another key question is what alternative service models could the company encourage remanufacturing at a greater level.

3.1 Overview on the case study

The conducted case study consists of a process analysis. Subject to this analysis are the Company X's reverse logistics and remanufacturing process. Figure 10 shows the three major stages of the conducted analysis.

Figure 10: Stages of the process analysis

Phase one aims to understand the general processes and underlying structure of Company X. It also is intended to get to know local conditions and contact persons. Phase two has the goal of collecting data about how processes are currently executed and it consists of two basic sources of information:

- Observations at Company X
- Analysis of already existing data

In this phase a value-stream-analysis (VSA) is employed to map the current state and highlight processes that produce waste. An insight on the theoretical background of the value stream approach is given in section 2.5.

The previously collected data is analyzed during phase three. It is desired to determine the cost of remanufacturing operations, and to find weak points in the current workflow and organization. Once the data is collected and analyzed, the current processes can be improved. Figure 11 shows the three major aspects that will be considered.

Figure 11: Three dimensions off improvement in the present process

Finally, the developed improvement approaches are checked for their applicability in the existing manufacturing system. Depending on their complexity and acceptance, they will be implemented and evaluated by the end of this thesis to make a conclusion about their actual effectiveness.

3.2 Company X's profile

This chapter gives an impression of how the company, which is the subject of the conducted case study, is structured and what its sales markets are.

Company X is a medium sized enterprise that produces industrial equipment for the construction sector and manufacturing industry. It is located in Rhode Island, USA, where it designs and manufactures its products. A call center, where the customer service representatives (CSR) are located, is close to the shop floor and repair station. The main sales market is within the United States. However, it also supplies foreign markets, above all the Canadian market, where it maintains a warehouse. From here, Canadian customers are supplied, in order to reduce the time between the customer's order and delivery. This ensures a short lead time, while the stock is replenished by larger deliveries with a longer lead time. Company X produces more than 1300 different

part numbers in a mixed production. Operating with such high product diversity relies on a very well controlled production system. This is achieved by focusing on lean production principles to produce profitably and satisfactory for the customer. The current condition of the repair station does not comply with the basic principles of lean production yet. This is indicated by the ratio of process time and lead time, long waiting times, high inventory and the sequence of processing incoming units to name some factors. The repair station is subordinated to other processes, as production control focusses on the actual production of new goods and their motto for allocating resources is “*production comes first.*” Hence, the repair station was neglected, while improving the production of new products in the past. Today, this station causes large inventory and customer dissatisfaction, due to long waiting times.

3.3 Possible product paths in the warranty returns process

During the process analysis at Company X’s production site, the path of returned products from gate to gate was recorded. Figure 12 shows which stages a product has to go through and which decisions are made to influence the way it takes.

Figure 12: Product path through warranty returns process

The return process starts with a customer's call to the customer service representative (CSR). The CSR initially collects information about the defect and about the purchase date to enhance handling of the returned unit. If the warranty is not expired yet, the CSR issues the customer a return goods authorization (RGA) so the customer can send his unit to Company X's. If the warranty is expired already, Company X offers repairing broken units for a flat fee that is predetermined for every part number. In this case, the CSR asks for billing information from a credit card or a purchase order number (PO#).

Once the broken product is delivered to Company X, it has to be transported to the repair station where it is opened and received. Here, the product has to be either repaired if it is a straight repair order, or to undergo a warranty evaluation. If the result is that the failure is covered by warranty, the unit gets repaired immediately. It also gets repaired right away, if the customer asked for a repair in case of a negative warranty evaluation result and provided billing information. If the customer did not give a repair order in case of a negative warranty evaluation outcome, the CSR contacts him to make a repair offer and to clarify how to proceed with the evaluated unit. Now, the customer has to decide whether he wants the product to be repaired or not. If yes, Company X repairs it and charges for that service, but if not, the unit gets scrapped. Currently, scrapped units are already screened for parts that might be used as spare parts. This is done by the repair shop operator and is seen as an activity that fills possible idle times, which are currently rare due to a backlog in evaluation and repair. A special case are emergency replacements. Company X makes exceptions for important customers, whose business depends on functioning equipment. If one of their units fails and production stops,

Company X sends them a replacement unit immediately without evaluating or repairing the failed unit as a gesture of good will. This is indicated by the “replacement box”, which is located behind the “scrap” box, since it replaces a unit that was not repaired. After a product is functioning again, it gets a new paint coating and is shipped back to the customer

As described in the company profile, the process for deliveries from the Canadian market differs from the standard procedure for products from American customers. Due to customs processing and tariffs, Company X collects returned units at their warehouse in Ontario and ships them to their plant in the United States in batches. This procedure requires extra handling and causes longer lead times. Another downside is the disruption caused by the arrival of large batches in the evaluation process flow and subsequent inventory increase.

3.4 Process data collection and analysis

Before starting to collect data on the shop floor, the existing process data from Company X’s data base needs to be investigated. The available warranty returns data covers a time period starting from the year 2010 to the present. This is due to an update of Company X’s process tracking software in 2010.

The provided historical data covers information about all processed items that were received at Company X’s plant as a warranty return, sorted by shipment number. Each shipment can contain more than one product. For each shipment, the provided spreadsheet contains 27 other data points, some of which are relevant for this study while some

are not. Customer related data shall not be analyzed in this case study, while receiving and shipment dates, part numbers, invoice totals are important for the process analysis.

The data analysis is mainly conducted with the software Microsoft Excel, using pivot tables to extract and sort relevant data.

Objective of this data analysis is to identify the warranty return process' condition and to prove the suspected bad performance in terms of adherence to promised lead times and to identify its cause.

Other required data is actually not related to the warranty returns process but to the production of new products. This includes the cost of manufacturing new units and their retail price. This data is needed to calculate the total cost of servicing different proposed warranty policies.

Another set of provided data is the results of an LCA that considers one of Company X's products. This product is one of the top three most frequent part numbers in the repair station, so it is used as a model to be generalized to assess the environmental impact of subsequently considered part numbers. Since the processes and machines that are used to make Company X's products are the same, this generalization is considered to be sufficient.

The data collection on the shop floor provides more detailed data in terms of work contents, processed quantities, and times that are needed to carry out certain tasks. In order to collect this data, it is necessary to spend time at the work station and to monitor the value stream in the manner it is described in section 2.5.1. The required material is pencil, paper and a stopwatch. In addition to observing, interviews with the people on

the shop floor is a source of information about the perceived vulnerabilities and measures to improve the current situation.

Once the data is collected and the historical data is analyzed, different warranty policies are proposed as alternatives for Company X. These alternatives are compared to each other in two different perspectives. First, cost calculations are made determine which policy is least costly or most beneficial. The following cost factors are considered in the calculation:

- Labor
- Cost of spare parts
- Manufacturing costs of replacement units
- Opportunity costs
- Revenue from fee-based repairs

Subsequently, the four proposed policies are investigated from the perspective of their environmental impact. This is done based on the data of an LCA that was conducted earlier at Company X's plant.

Based on the outcome of the warranty policy comparison, the value stream approach is employed to improve Company X's warranty processing.

4 FINDINGS AND DISCUSSION

The following section describes the findings of the conducted case study at Company X. First the results of the historical data analysis are presented. Then four different warranty policies are introduced and discussed. The most beneficial one for Company X is identified and modified to Company X's needs. Finally, the value stream approach is used to identify measures to improve Company X's warranty returns processing and concrete recommendations are made.

4.1 Analysis of historical data

This section deals with the findings from analyzing historic data of the repair station, which was provided by Company X. The analyzed data dates back to the year 2010 and is cut off at the end of 2015. Data from 2016 is not included, because it is desired to analyze a consistent annual time. In these five years, 318 different part numbers and 3172 units in total were processed in the repair station. To narrow down the scope and to focus on the critical issues, the three most frequent part numbers are selected for the detailed process analysis which is conducted subsequently. These three part numbers sum up to 658 units, which is 21-% of all processed units. In order to keep discretion, these products will be referred to as Part A, Part B and Part C, with Part A being the most frequent part number, Part B the second most frequent and Part C the third most frequent. Figure 13 shows that the average rate of selected returned part numbers exceeds the average of all part numbers, which is declining significantly in the observed period. This indicates that the selected products might have quality issues.

Figure 13: Rate of returned products over time

Figure 14: Shares of repairs covered and not covered by warranty

Figure 14 compares the amount of processed units that are covered by warranty and those that are not covered. Not covered are units are those which were not operated properly by the owner or simply out of the warranty period. The reason for the failure of warranty covered parts needs to be investigated. Company X cannot charge the owner for these repairs or replacements, so any processing of these units can be considered to be unprofitable. It is desired to reduce the amount of warranty covered parts to a

minimum. This could be done by investigating reasons for returns and improving manufacturing and assembly quality. However, a detailed failure analysis is not the scope of this study and may be a subject for future research.

Part Number	Number of returned units						Total
	2010	2011	2012	2013	2014	2015	
Part A	53	53	34	85	86	25	336
Part B	40	29	19	18	19	50	175
Part C	19	25	33	35	16	19	147
Total	112	107	86	138	121	94	658

Table 2: Volume of returned selected part numbers

Table 2 displays the number of processed units of the selected part numbers. Part A is processed almost twice as often as the other two part numbers.

To simplify the billing process for repairs, Company X bills the customer a predetermined price for every part number in case of a repair that is not covered by warranty, subsequently called a *straight repair*.

Figure 15 shows the predetermined prices for straight repairs of the three selected part numbers and the average for all processed part numbers in comparison. One objective of this research is to determine the actual average cost of repairing a returned unit.

Figure 15: Predetermined repair fees per unit

Company X aims to shorten their lead time in the repair station, to offer the customer a “*Same Day – Next Day*” (SDND) service. This means that a received good will be processed and shipped back by the next day at the latest. This objective is meant to be an attractive service to the customer and has to be achieved with a lean remanufacturing process. The following description of lead times refers to all processed part numbers, not only the top three models.

Figure 16: Share of the two most frequently promised lead times

Currently, the average lead time is 21.67 days with a standard deviation of 34.95 days (excluding a few outliers that might be typing errors due to sloppy recording). The actual lead time of 15 days differs from the two mostly promised lead times of 7 day and 14 days, with an average of 8.7, including SDND orders (Figure 16). A promised lead time of zero days is a SDND order, which are one tenth of all turned in units.

Figure 17: Percentage of late and in time (EOT) units

Less than half of all units are processed in the promised time. As Figure 17 shows, only 37 % of all returned units are processed in time, regardless of their promised lead time. This includes SDND orders as well as standard returns. This yield might cause customer dissatisfaction, since a late unit may delay the customer's production processes, which means high costs and lost profit.

Figure 18: Number units over actual lead time

Figure 18 shows that the actual lead time scatter plot rather than the promised lead time in Figure 16. The first peak reaches 123 units at zero days actual lead time. These units are SDND repairs, which are not late. The second time the curve peaks with 125 units at seven days, which is also the most occurring promised lead time. The curve shows another peak at 14 days, however it only rises up to 69. After an actual lead time of 30 days, the graph does not climb higher than 20 and stays close to the horizontal axis. The longest recorded actual lead time is noted as 342 days and is not shown in Figure 18. This extreme value might be an outlier that is due to a recording error. However, it is important to notice that some products stay in the work shop for much longer than the average promised lead time.

Figure 19: Average promised and actual lead times and days early/late

Comparing the average lead times in Figure 19, it is obvious that the actual lead time differs significantly from the average promised lead time. The average lateness of 12.94 days is the average time difference between promised and actual lead time of all shippings. It indicates that the processing of returned products needs to be enhanced, because the current backlog causes high inventory and customer dissatisfaction.

Figure 20: Lead time comparison of warranty covered and not covered parts

Comparing the average lead times of returned units that are covered and units that are not covered by warranty, a significant difference can be observed. In case of a given warranty repair, the CSR promises a longer lead time, while straight repairs and not covered warranty returns are given a shorter lead time. Due to failed warranty evaluation

and pending repair order, some units' lead time extends to weeks or even months. This causes the larger gap between the promised and the actual lead time.

Company X classified the analyzed data to be containing all processed goods, so it gives a good overview on the volume and its development over time. Nevertheless, there are some signs that there might have been mistakes occurring while entering data into the computer or inaccurate recording. The negative lead times in Figure 18 indicate that interpretations of the analyzed data might not be completely reliably.

The analyzed data also shows that the amount of returning products increases slightly over time, which is not caused by a declining quality but an overall growing production volume. An indicator for increasing quality is the shrinking rate of returned products compared to the volume of newly manufactured products.

Returning products from abroad, with Canada being the only significant foreign market, are treated differently than domestically sold units. Company X maintains a warehouse in Ontario, Canada. From here, Company X's products are distributed to dealers and customers in Canada. In the event of a failure, the returning product needs to be sent to the warehouse, where it is stored. This stock of products for repair or warranty evaluation is send to Company X's plant in Rhode Island, USA, as soon as a reasonable amount of units is collected. The reason for this procedure is that shipping all products separately would cost significantly more, due to tariffs on international shippings between Canada and the United States of America. The share of returns from Canada accounts for 7.61-% of all returns, while 91.83-% come from customers and dealers within the United States. This small share of the total volume causes an unproportional amount of work, since it has to be handled more than usual returns.

Another effect is that it arrives in batches which disturbs the process. The sporadic arrival of a large number of units produces a backlog, which is delaying the processing of units from domestic customers.

The actual process time of how long it takes to process a warranty return from Canada could not be provided by Company X, since no corresponding data exists.

4.2 Discussion of alternative warranty policies

The current warranty policy of Company X is a non-renewing free repair warranty (NRFRW). To increase Company X's market share and to realize growth in the future, customers have to be retained. Even though the given warranty does not include any delay penalties, chronic tardiness damages Company X's business. Non-fulfillment of quoted lead times for warranty evaluation or repairs damages Company X's reputation, which drives customers to balk.

Company X sees its current warranty policy as critical, because it causes high costs due to large inventory, material handling and communication volume that could be used for manufacturing and sales of new products.

From a lean perspective, rework like evaluating and repairing can be considered as muda, since this work is not value added but time and labor intensive. In this following chapter, three different alternative strategies for dealing with warranty returns are discussed. These alternatives are:

1. Non-renewing free replacement without evaluation (NRFRWNE)
2. Non-renewing free replacement warranty without repairs (NRFRWNR)

3. Non-renewing free repair warranty (NRFRW) plus fee-based repairs of not covered failures
4. Non-renewing free repair warranty with Canada replacements (NRFRWCR)

The following considerations are made based on the historical data of the top three returned part numbers and only for the year 2015.

4.2.1 The non-renewing free replacement warranty without evaluation

Alternative one the NRFRWNE represents the most radical change from the current system and is a rather theoretical approach. Discontinuing warranty evaluations would change the process of dealing with warranty claims in a way that gives away control but cuts the lead time and sets resources free.

Figure 21: Alternative warranty policy one

This kind of warranty strategy has the advantage of causing the least amount of processing and handling. As shown in Figure 21, the only instances involved in this process are the CSR and the shipping station. A typical warranty case processing would look as follows. As soon as the customer notifies the CSR about a failed unit, the CSR determines if the respective unit is still in the warranty period. If so, he orders the shipping station to pack and send a replacement unit to the customer. This strategy is characterized by the shortest possible lead time, so Company X would not have to struggle offering an SDND service and the customer would receive the best possible service.

Besides the improved customer service, the unused resources could be used differently, for value-added activities. This includes the operator's labor, since he would not have to investigate failures and repair returned units but could instead assemble new units. The reduced workload in communicating with the customer and the operator in the warranty returns station provides the CSR with more time for new customer acquisition and sales.

The flipside of this strategy is that there is hardly any control on who is responsible for a product failure. Company X would have to take the risk of end users taking advantage of this warranty policy, since it is based on trust. Therefore, it makes it easy for customers to call and ask for a replacement unit even if the initially purchased unit has not failed. Another disadvantage is the lack of analysis for in-field failures, because failed products are not returned to Company X to be investigated. Thus, systematic problems that affect product quality might not be identified and corrected, leading to continuing warranty replacements on future units.

Warranty Policy #1 : Non renewing free replacement - no evaluation	
Cost of Opportunity	\$ (28,141.19)
Manufacturing Cost	\$ (15,253.11)
Repair Revenue	\$ -
Evaluation Cost	\$ -
Repair Cost	\$ -
Spare Part Cost	\$ -
Total	\$ (43,394.30)

Table 3: Cost for maintaining policy #1, based on 2015 data

4.2.2 Non-renewing free replacement warranty without repairs

Warranty policy alternative number two, the NRFRWNR, provides free replacement with a new unit, and however aims to eliminate the risk of a wrongly notified failure, because the customer is required to send in the failed unit to undergo an evaluation. In the meantime, Company X sends out a replacement immediately. Based on the outcome of the warranty evaluation, Company X charges the customer for the replacement unit. Just as in alternative policy one, number two is characterized by a short lead time, however with a reduced risk of warranty fraud. This policy's disadvantage is that it requires labor to investigate failures. Nevertheless, the amount of required labor is less compared to the current process, since no time-consuming repair needs to be executed.

flow in order to reduce lead times and improve customer service. This is particularly important, since Ramanathan (2011) found in his research on e-commerce, that a significant amount of customer dissatisfaction is generated by late arrivals of a product or damaged products. To cope with delivery failures, a dedicated customer support team needs to be available immediately. Using levers like refunding delivery costs, providing discounts or refunding a faulty product, customer support can turn a negative purchase experience into a positive customer service experience.

The reduction of costs and, more important, the improvement of customer service is calculated in section 4.3 of this study.

Warranty policy #3: Non-renewing free repair	
Cost of Opportunity	\$ -
Manufacturing Cost	\$ -
Repair Revenue	\$ 10,373.99
Evaluation Cost	\$ (612.27)
Repair Cost	\$ (1,422.93)
Spare Part Cost	\$ (798.03)
Total	\$ 7,540.76

Table 5: Cost for maintaining policy #3, based on 2015 data

4.2.4 Non-renewing free repair warranty with Canada replacements

The fourth analyzed warranty policy (NRFRWCR) is a combination of alternative #2 and #3, applying NRFRWNR to the Canadian market and a NRFRW to the U.S. market.

The current practice of batching units at the Canadian warehouse to ship them to the plant in the United States was implemented to reduce cost and effort at customs. In order to benefit from this procedure in the future but to reduce lead time of warranty

claims processing and customer dissatisfaction, Company X needs to introduce a credit system, which allows the warehouse in Canada to send customers a new unit immediately. This unit is billed to the customer, but he retains the right to receive credit for the failed unit after analysis is complete. When the failed units are turned in, they can be collected at the warehouse and shipped to the plant as a bundle, while the customer can proceed with his production. Depending on the outcome of the subsequent warranty evaluation, Company X gives credit for the failed unit.

If a Canadian customer asks for a fee-based repair, the procedure is different. In this case, Company X cannot supply a new unit in exchange for a used one, so the customer has either to accept a longer lead time or to pay an extra fee, for express shipping that covers the expenses for shipping a smaller batch immediately.

Warranty policy #4: Non-renewing free replacement for Canada			
CANADA		USA	Combined
Cost of Opportunity	\$ (1,276.40)	\$ -	\$ (1,276.40)
Manufacturing Cost	\$ (772.36)	\$ -	\$ (772.36)
Repair Revenue	\$ -	\$ 9,369.79	\$ 9,369.79
Evaluation Cost	\$ (66.97)	\$ (545.30)	\$ (612.27)
Repair Cost	\$ -	\$ (1,267.30)	\$ (1,267.30)
Spare Part Cost	\$ -	\$ (704.04)	\$ (704.04)
Total	\$ (2,115.73)	\$ 6,853.15	\$ 4,737.42

Table 6: Cost for maintaining policy #4, based on 2015 data

Figure 23 compares the yearly costs of maintaining each proposed warranty policy. Particularly the cost of opportunity sticks out on the lower side of the horizontal axis. The first two analyzed warranty policies are characterized by higher costs of opportunity, while policies #3 and #4 generate revenue through repairs. This revenue

even compensates the cost of opportunity and process costs, so the total costs for these two policies actually represent a positive cash flow.

Figure 23: Comparison of analyzed warranty policies

Alternatives three and four perform not only better in an economical view, they are more environmentally friendly as well. The lower consumption of new manufactured units by Company X significantly reduces the consumption of resources and energy and

therefore causes less emissions. One of Company X's products, in this paper referred to as part number B, was subject to an LCA, conducted by Nörmann (2015). This investigation yielded that the major share (90 %) of the products total environmental impact is generated in the raw material phase. This phase includes casting processes that are characterized by a high energy consumption. The machining of parts contributes another 8 % of the environmental impact. Figure 24 shows that processes that are carried out to maintain warranty policy number three or four are hardly causing a negative environmental impact, compared to the manufacturing of new parts. Processes in the warranty returns line are:

- Assembly. Disassembly, evaluation and repair. Then reassembly and test.
- Painting, including the preparation and postprocessing

In contrast to this, the more energy and resource consuming processes that are carried out to manufacture a new product or new parts are for example:

- Smelting, to produce raw material
- Metal casting, forming parts like housings
- Machining raw material or metal casted parts
- Welding to fit parts together

Figure 24 displays the environmental impact of each process that is carried out in Company X's plant in the equivalent to kg of CO₂ to make them comparable. Assembly and painting, the two processes that are most often included in the repair process are less environmentally significant than machining processes. It is important to notice that the production of individual spare parts is not significantly influencing this

consideration. Nevertheless, in the rare case of a failed housing, the production of a spare part would certainly influence the the environmental impact balance of the repair process, since it is the most environmentally impacting part of every unit. In conclusion, this means that the environmental impacts of warranty policy three and four are about 98-% lower compared to warranty policy one and two.

Figure 24: LCA results, without material production (Nörmann 2015)

4.3 Application of the value stream approach – the analysis phase

Since the most beneficial warranty policy was the third proposed alternative (NRFRW), it is proposed that Company X keeps on repairing returned products. To do this more profitably, the current process needs to be improved. The value stream approach is employed to enhance the current process' performance.

The first step of a value stream analysis is choosing a product family and getting familiar with its production procedure. The selected part family are all returned products that undergo a warranty evaluation or repair, since they all follow the same material

flow. Now the selected value stream needs to be mapped on a sheet of A3 paper (11 x 17 inches). Now, a data box for the production planning and control (PPC), which is the same person as the CSR in this case, is drawn in the center of the sheet (see Figure 25). The supplier's factory, in this case Company X's customer with a defective unit, is drawn in the upper left corner. The customer's factory, in this case the same factory as the one that is supplying the defective unit, is positioned in the upper right corner. This allows a linear value stream to be drawn, with easily understandable information flow that visualizes Company X located in the middle of a product flow from supplier to customer.

Figure 25: Positioning Company X, Supplier and Customer Plant on VSM

The CSR is responsible for the entire communication with the customer. Company X's warranty policy requires the customer to notify the CSR or the dealer within 30 days after the discovery of a failure. This is mapped as an electronic information flow arrow from the customer to the CSR. As soon as they report the failure, the CSR starts evaluating if he is dealing with a warranty return or a straight repair. The result influences the following procedure. The decisions, which are made based on the collected information, are explained in section 3.3. After the customer notifies Company X of the failure, the CSR issues him an RGA number so he can proceed and send the defective unit to Company X's plant (see Figure 26). This transport is noted as a shipping arrow from the supplier's plant to Company X.

Figure 26: Communication between CSR and customer and delivery

The data collection was started at the end of the material flow, the shipping station, and followed backwards. In order to make the process more transparent, it is listed subsequently in the order of a defective unit passing through.

After arriving at the plant, the packet stays in the shipping station, where it was delivered. Once a day, the material handler comes and picks up all warranty returns to transport them to the repair station. This is indicated by a push arrow, since it is done daily, independently from the customer process' need. At the workstation, the packets usually build up some inventory, since they are brought here once a day and wait unopened before getting processed. The arrived units are processed in a certain order, where straight repairs have priority, because they can be examined and repaired in the same operation, whereas warranty evaluations might have to wait until the customer orders the repair if no warranty coverage is given.

The examination and repair process is executed in the following steps. First, the packet is opened and the unit taken out. Then, the operator receives it, and attaches a tag to it, to make it easily identifiable later on. This tag says if the unit is a warranty evaluation or a straight repair, and it also shows the RGA number and a bar code. The reception of one unit takes 270 s (4 minutes and 30 seconds). This is the point when the unit has officially arrived at Company X, so from here, the actual lead time, which was analyzed in section 4.1, starts counting. Therefore, the analyzed actual lead time is not the true lead time, because it does not include the time between arrival and reception, which can be up to two days (see Figure 27).

Figure 27: Entry into the repair station

Once the reception is finished, the failure evaluation can begin. This part extraordinarily depends on the skills of the operator, due to the occurring product diversity and failure variety. A well trained and experienced operator is not only crucial for the failure detection and repair, but especially for the interpretation and cause investigation, which results in a given or not given warranty.

Based on the information that was provided by the customer, the operator proceeds to investigate the defect. Manifold stages of disassembly can be necessary to find it, which results in varying process times. The following factors influence the process time significantly:

- Product type

- Failure type / failed part
- Product condition

Company X sells more than 1300 different part numbers, varying in size, function, drive power, and materials and they are powered by pneumatic, electric (AC or DC) or hydraulic drives. This broad range of occurring goods provides a high number of possible parts for failure, some of which are easy to access while others require total disassembly.

The failure type is not only crucial because of different levels of work load that are needed to repair a failure, but also the difficulty of detecting it. Some failures are obvious, such as a broken housing or bearing. Others are less easy to detect and need measuring and testing, such as locating short circuits.

The unit's condition influences the process time significantly. Some units are sent back in an as-new condition, while some others have been in service for a long time and are covered in cement or corroded. This multiplies the required disassembly effort.

When the failure evaluation is finished, the operator determines if a repair is covered by warranty or not. As explained in section 3.3, the unit may have to wait for the customer's consent to a repair, if the warranty evaluation yielded a negative result. The electronic information flow arrow from the inspection process data box to the PPC data box is the visualization of the operator notifying the CSR that the evaluated unit is not covered by warranty. The CSR then contacts the customer and asks if he is interested in a fee-based repair or a new product. This is also the case if the investigated failure is

not covered and the product is beyond reasonable repair, due to age or severity of damage.

Depending on the result and on the customer's decision to have it repaired or not, the unit may have to wait to be processed further. This causes high inventory and an untidy looking work station, since there is no designated storage facility for waiting units. If it is not possible to repair a unit reasonably or if the owner decides not to pay for a repair, it is moved into the scrap container. These units wait to get scrapped or recycled. Recycling scrapped parts is not a controlled process, but a side activity. If the operator of the repair station needs a spare part from a unit that is in the scrap container and easily accessible, it is used in place of a new part. A benefit of handling the recycling process this way is that the repair station operator is never idle. On the other hand, it is time consuming to disassemble spare parts from scrapped units, while the repair process falls behind schedule and builds up inventory. Since this is usually the case, no units are currently recycled, hence this process is not further considered in the value stream map.

If the owner orders the repair of a waiting unit, he contacts the CSR, who forwards the repair order to the repair station, where the repair is scheduled.

The actual repair is executed in the same workplace as the evaluation. Just as the disassembly and evaluation, its duration varies depending on the following factors:

- Product type
- Failure type / failed part
- Product condition
- Spare part availability

The first three factors affect the repairing and assembling process in the same way as the disassembly and evaluation. Due to the high number of different part numbers occurring in warranty returns, it is unreasonable to provide all single parts of all products at the work station. Therefore the operator has to walk to the respective assembly station in the manufacturing department to pick up the required replacement for a broken part from time to time. Nevertheless, the provided spare part inventory at the warranty returns work station covers the most frequently occurring replacements. After one product is repaired and tested, it gets cleaned, stickers removed and put on a conveyor belt to transport it to the paint shop. The time for this step is also included in the repairing time. Depending on the product type, this step in the repairing procedure is not consistent. Smaller units or units that were sent in by the same owner are collected in batches on a cart and then transported to the belt. The average cycle time in repairing is 1720 s (29 minutes), including a test run and occasionally spare parts not being ready at the work station.

Figure 28: Complete repair station with the split material flow

The finished units still need to get painted. Since there is no extra paint shop for repaired units, the repairing material flow merges into the production material flow. To line up for painting, repaired products are put on a conveyor belt, that brings them into the paint shop in the order they were put on.

Units that need to be shipped urgently can skip the waiting time on the belt. In order to make this possible, the operator has to enter the paint shop and ask the operator to work on the repaired unit first. This causes a delay in the actual production flow and violates the motto *production first*. Nevertheless, some newly produced products, which have priority, can skip the conveyor belt as well. Due to the frequent occurrence of products skipping the conveyor, it moves extremely slowly, with an inconsistent speed.

However, Company X is currently working on improving this situation in the paint shop, as well as removing bottlenecks in the packing and shipping stations. Therefore these steps in the process shall not be considered furthermore during this study.

After being painted, the unit dries in a drying rack before it gets forwarded to the shipping station. Here, it is packed into a cardboard box and shipped back to its owner. On the VSM, the shipping process is again symbolized by the shipping arrow with the schematic truck icon on it (Figure 29).

Figure 29: Complete current state VSM

4.4 Application of the value stream approach – the design phase

Now that the current value stream has been analyzed and mapped, phase two of the value stream approach starts, which is the value stream design phase. The objective is

to determine how the production flow can be improved and the process made more efficient.

Figure 30 shows the completed current state VSM. The red Kaizen lightning bursts indicate points where the value stream is interrupted or disturbed. The Guidelines 1 – 7 from section 2.5.2 can be employed to provide methods or strategies in order to improve the situation at these points.

Figure 30: VSM with Kaizen lightning bursts

Company X's warranty returns processing is characterized by a significant gap between the promised lead time and the actual lead time. This causes a late delivery of over 60 % of all processed units.

This delay is caused by several various nuisances in the value stream that depend on each other. However, it is not clear which is the cause and which is the effect. The following section discusses the Kaizen lightning bursts in Figure 30:

Starting from the arrival of the units at Company X, the first lightning burst indicates the inconsistent pick-up of arrived packets at the receiving station. It is supposed to happen once a day, however, depending on the repair shop operator's capacity, packets wait for the pick-up for up to one additional day. In order to change this, the downstream processes need to be improved. Due to the high inventory in the repair station, the operator lacks capacity for transportation and focusses on processing local units.

The late reception of packets is an effect of the current work flow. As long as packets are not transported to the repair station, they do not appear as present in the RGA, even though they were delivered already. In order to close the gap between delivery and reception, incoming units would have to be unpacked immediately. This would cause an increased amount of handling for carrying out a non-value added activity. The current backlog in the overall process is causing longer waiting times in this process step, so it is to be evaluated if adding another activity would help to improve the material flow. The advantage of the current method (receiving right before the warranty evaluation) is that received units get evaluated immediately, which is beneficial for the process flow (see Guideline 2), so the present inventory should decrease as soon as a bottleneck downstream is eliminated.

The current value stream contains high inventory of units that have already been evaluated and were not given coverage by warranty. These units wait for a repair order

from the owner and take up space in the work station. At this point, the units are already disassembled, hence they take up even more space and provide the possibility of getting confused with each other. Additionally, it makes the work station look untidy, which violates the lean principles of 5S for workplace organization (sort, set in place, shine, standardize, sustain). A modified Kanban supermarket can help to structure the storage of waiting units. Instead of putting evaluated units on carts and workbenches, they should be stored in a designated shelf with boxes. Each of these boxes should hold one unit with all of its components. Similar to a Kanban supermarket, the customer order triggers the repair of a certain unit. Since the supermarket does not solve the problem of high inventory and long waiting times, which are due to late customer responses, another adjustment has to be made. In order to avoid extremely long waiting periods, a maximum of tolerated time spent in the repair shop has to be determined. A measure to reach this goal is implementing a time fence in the warranty policy that provides the customer a certain period of time after receiving the warranty evaluation result to react. This may be seven business days for example. If the customer does not order a repair or issues the permission to scrap his unit, it should be shipped back to clear space in the work shop.

After being repaired, every product gets a new paint coating. Before entering the paint shop, the repair station's material flow merges with the actual manufacturing material flow. The slow conveyor belt speed is both, cause and effect of the long waiting time before painting. Since the conveyor is moving so slow, urgent deliveries skip it and enter the paint shop directly. Since the paint shop operator is spending more and more time on priority units, the conveyor belt advances even slower, which causes backups

and creates more incentive to prioritize orders. To break this circle, the criteria for priority need to be set higher, so most units get placed on the conveyor and advance constantly towards the paint shop.

One of the causes of high inventory in the packing station is a lack of capacity, since the packers cannot cope with the paint shop's output. However, these processes are currently being investigated by Company X and shall not be specifically considered in this study, since they are part of the forward supply chain of new products.

The repair station as a whole is facing a constantly high inventory, while lacking capacity to cope with the amount of incoming products. The time fence on waiting time is one measure to reduce the amount of waiting units. Nevertheless, this work station is characterized by a high workload that needs to be reduced to a normal level. In order to achieve this, another change in warranty policy is needed, so a part of the repair station's work content can be eliminated or moved to another phase of the warranty returns process (see Figure 31)

Figure 31: Moving work content out of the repair station

Since the actual repair has to be carried out at the repair station, the objective is to reduce the volume by evaluating failed units earlier. Failures that are due to improper use, which contribute a significant amount of not covered repairs, can be detected

visually while the failed unit is still mounted at the customer's facility. Company X's warranty policy needs to contain the requirement of submitting a photo of the mounted unit along with the failure notification. This would allow the CSR to evaluate if the customer mounted it improperly and, if so, give him a quote for a fee-based repair or new product.

Another share of units that is waiting for processing in the repair shop was sent in as a straight repair. The evaluation yielded a condition that is beyond reasonable repair (BRR), which can be due to the severity of a failure or to the product's age. In case of a fee-based repair, a unit is classified as BRR if the cost for processing it are significantly exceeding the amount of the flat repair fee. Other units cannot be repaired because of a lack of replacement parts due to design changes or discontinued manufacturing.

To reduce the number of BRR units in the repair station, the CSR needs to be given a guideline to assess the probability of a BRR classification before issuing an RGA.

One measure to sort out BRR units can be the estimated lifetime. Moving parts in Company X's products are designed to last for a certain number of load cycles or rotations of ball bearings for example. Given an average usage rate, this results into an estimated average life time. With access to predicted life time data of product families, the CSR would be able to detect BRR units ahead of the evaluation in the repair shop.

Figure 32: Future state VSM

Figure 32 shows the future state value stream with implemented changes in the processing of warranties. Instead of just notifying a failure, the customer now submits a photo of the unit's installation. This helps the CSR to decide on whether to issue an RGA or a quote for a new product. Even though this is an additional task for the CSR, the total occupation with warranty processing is reduced by the time fence that is limiting the period a product can wait for a repair order. Thanks to this measure, the CSR does not have to try to get in touch with the customer to determine how to proceed with an evaluated unit, which takes a significant amount of time, in order to find out how to progress with his units.

Inside the repair station, there is a supermarket that contains all waiting units, each in a separate box. This ensures that they are easy to find and not getting confused with each other or taking up workspace that can be used for repairs. Units that exceed the tolerated waiting period are moved from the supermarket to the recycling container. The pull arrow between the supermarket and the repair process indicates that the material is pulled out of the supermarket when the operator receives a repair order from the CSR.

4.5 Using Remanufactured-product as replacements for reduced price

The following section explores whether Company X should adopt remanufacturing and storage of returned products to send them out as warranty replacements.

Section 4.2 shows that a strong counter argument against replacing failed units with new ones is the cost of opportunity, since a unit that is given away as a free replacement does not generate any revenue. Concerning the costs, it is more expensive to manufacture a new unit than to repair a returned one. Also, scrapping returned units, or only using one or two parts as spare parts for other units is a waste of material and value because effort has already been put into the production of these products. Besides the economic justification, it is more sustainable to make use of available parts on one of the earliest stages in the reverse logistics chain. Applied to this case study, this means Company X would repair failed parts in a returned unit with the least amount of disassembly and fabrication. The objective is to create a working product with the quality of a newly manufactured one, though with a minimal number of new parts. Since Company X does not intend to start the sale and distribution of remanufactured products, these products are limited to serve as replacement units for failed units in case of an

emergency replacement. This would add another path into the warranty returns process in Figure 12. Figure 33 shows how remanufactured units could be employed to serve as replacement units.

Figure 33: Product path with remanufactured replacement option

Despite the economic and environmental savings of this approach, there are arguments against it, notably the low volume of available cores. Due to the rare occurrence of products that stay at Company X because they were replaced by a new product, the pool of remanufactured units in storage will be small. This reduces the likelihood of having the right remanufactured product in stock if a customer needs his failed unit replaced immediately, since Company X sells more than 1300 different part numbers. A low probability of having the right unit in a seldom occurring case also means that the units in stock have to be stored for a long time until they might get used to replace a unit at a customer's plant.

5 CONCLUSION

This study was conducted to investigate the profitability of remanufacturing processes in small and medium sized companies. The first part deals with the importance of moving towards a more sustainable production style and reviews methods from the literature that can help to realize this change. The second part consists of a case study that was conducted in a medium sized company, focusing on their warranties returns processing and opportunities for manufacturing.

First, the reader was introduced to the idea of reusing manufactured parts in order to save costs and increase sustainability. Methodological life cycle thinking is used to plan a product's life cycle ahead, so it can serve as a resource for a new product at the end of its useful life. Methods to assess a product's environmental impact and to increase its remanufacturing potential are described subsequently. Section 2.3 describes how a remanufacturing process looks, how the supply works and how it can be integrated into existing production. The final part of the literature review prepares the reader for the conducted case study, dealing with the theoretical background of warranty policies and the importance of lean thinking in shaping value streams.

Following the theoretical part, the case study starts with a brief portrait of Company X and their warranty returns processing of failed products. The historical data analysis was conducted to determine the condition of the current warranty returns process. The analysis yielded a tendency to long lead times and deviation from promised delivery dates. In order to improve Company X's performance in this field, four different warranty policies were discussed and a cost calculation yielded that the economically and ecologically most beneficial one is repairing returned units in an improved current

state process. Subsequently, concrete suggestions were made on how to enhance the production flow of the current repair process.

The scope of this study was to show that remanufacturing is not only sustainable but also economically beneficial. Small and medium sized companies hesitate to take on remanufacturing operations, due to a lack of knowledge and high investments into a reverse supply chain and establishment of remanufacturing production line. At the same time, large corporations already recognized the potential profitability of such activities and established remanufacturing production lines and supply chains that are operating profitably. Examples of successful remanufacturing businesses are found in the automotive or cellphone industry.

Through the example of warranty returns processing at Company X, this study shows that repairing used products can also be beneficial for smaller companies, even though approximately half of the carried out remanufacturing operations are billed to the customer in this example, since the others are covered by warranty. Repairing units saves costs for replacing failed units with new ones in the first place. The revenue created by fee-based repairs compensates not only the costs for repairing all returned units but also generates profit.

In contrast to other businesses, Company X is not operating an independent remanufacturing line or remanufacturing department, since it is coping with catching up with growing demand for new products. Due to the low volume of returned parts that do not stay in the customer's ownership, it is not economically reasonable for Company X to run a remanufacturing business that restores returned parts to like-new condition and sells them again. Therefore, the establishment of a core collection system

was not considered during the case study. The development of a remanufacturing business model or remanufacturing service at Company X, including the planning and implementation of a reverse supply chain and an independent remanufacturing division could be the subject of future research. This would be, taking Company X's current business situation into account, a rather theoretical approach.

The results of this case study have to be seen critically due to two limitations. First, the cost calculations were based on the three most frequent part numbers, and did not include all possible occurring part numbers. Another point that has to be considered as a source of deviation from true actual costs is the usage of average process times for all products. These times were selected for the cost calculation to make them more applicable to the everyday mix of production in the repair shop. Due to the wide range of part numbers and rare occurrence of some, not all individuals were taken into account to calculate average process times. Nevertheless, the applied times were estimated to be close to the true average.

Since a systematic failure analysis of returned products exceeded the scope of this study, it is proposed to conduct research in this area in the future. The three most frequently returned products are characterized by a significantly higher failure rate than Company X's average. This study could also employ design for remanufacturing methods when proposing changes in the product's design.

The findings of this study indicate that remanufacturing processes can be profitable for small and medium sized companies, while being environmentally friendlier than classic manufacturing. Measures to enhance profitable remanufacturing operations are an efficient reverse logistics system that relies on effective communication between

stakeholders, operational excellence in processing returns and the consideration of remanufacturing issues during the design stage. By considering these criteria, remanufacturing needs to be persuaded by a growing number of manufacturers to secure sustainable economic growth and to allow them to meet the constantly increasing consumption of industrial goods in the future.

6 APPENDIX

Calculation of warranty policy costs

Warranty Policy #1 : Non-renewing free replacement without evaluation (NRFRWNE)				
Part#	Part A	Part B	Part C	Total
# covered	5	45	14	
# not covered	0	0	0	
Repair List Price [\$]	\$ -	\$ -	\$ -	
Ag. spare Part cost [\$]	\$ (2.25)	\$ (15.29)	\$ (7.05)	
Total Ag. spare Part cost [\$]	\$ -	\$ -	\$ -	
Eval cost [\$ /h]	\$ -	\$ -	\$ -	
Repair cost [\$ /h]	\$ -	\$ -	\$ -	
Total Cost Eval. [\$]	\$ -	\$ -	\$ -	
Total Cost Rep. [\$]	\$ -	\$ -	\$ -	
Repair rev. [\$]	\$ -	\$ -	\$ -	
Total process cost [\$]	\$ -	\$ -	\$ -	
Grand Total mfg [\$ /Unit]	\$ (24.76)	\$ (257.45)	\$ (253.14)	
Sum mfg cost [\$]	\$ (123.82)	\$ (11,585.34)	\$ (3,543.95)	\$ (15,253.11)
List price [\$]	\$ 182.82	\$ 682.92	\$ 839.20	
Sum List Price [\$]	\$ 914.10	\$ 30,731.40	\$ 11,748.80	\$ 43,394.30
Opport. Cost [\$] (Lost rev)	\$ (790.28)	\$ (19,146.06)	\$ (8,204.85)	\$ (28,141.19)
Combined cost of repl. [\$]	\$ (914.10)	\$ (30,731.40)	\$ (11,748.80)	\$ (43,394.30)

Warranty Policy #1	
Cost of Opportunity	\$ (28,141.19)
Manufacturing Cost	\$ (15,253.11)
Repair Revenue	\$ -
Evaluation Cost	\$ -
Repair Cost	\$ -
Spare Part Cost	\$ -
Total	\$ (43,394.30)

Warranty policy #2: Non-renewing free replacement without repairs (NRFRWNR)				
Part#	Part A	Part B	Part C	Total
# covered	1	29	3	
# not covered	4	16	11	
Repair List Price [\$]	\$ -	\$ -	\$ -	
Ag. spare Part cost [\$]	\$ (2.25)	\$ (15.29)	\$ (7.05)	
Total Ag. spare Part cost [\$]	\$ -	\$ -	\$ -	
Eval cost [\$/h]	\$ (9.57)	\$ (9.57)	\$ (9.57)	
Repair cost [\$/h]	\$ -	\$ -	\$ -	
Total Cost Eval. [\$]	\$ (47.83)	\$ (430.50)	\$ (133.93)	\$ (612.27)
Total Cost Rep. [\$]	\$ -	\$ -	\$ -	
Repair rev. [\$]	\$ -	\$ -	\$ -	
Total process cost [\$]	\$ -	\$ -	\$ -	
Grand Total mfg [\$/Unit]	\$ (24.76)	\$ (257.45)	\$ (253.14)	
Sum mfg cost [\$]	\$ (24.76)	\$ (7,466.11)	\$ (759.42)	\$ (8,250.29)
List price [\$]	\$ 182.82	\$ 682.92	\$ 839.20	\$ -
Sum List Price [\$]	\$ 182.82	\$ 19,804.68	\$ 2,517.60	\$ 22,505.10
Opport. Cost [\$]	\$ (158.06)	\$ (12,338.57)	\$ (1,758.18)	\$ (14,254.81)
Combined cost of repl. [\$]	\$ (182.82)	\$ (19,804.68)	\$ (2,517.60)	\$ -

Warranty policy #2	
Cost of Opportunity	\$ (14,254.81)
Manufacturing Cost	\$ (8,250.29)
Repair Revenue	\$ -
Evaluation Cost	\$ (612.27)
Repair Cost	\$ -
Spare Part Cost	\$ -
Total	\$ (23,117.37)

Warranty policy #3: Non-renewing free repair warranty (NRFRW) plus fee-based repairs of not covered failures				
Part#	Part A	Part B	Part C	Total
# covered	1	16	11	
# not covered	4	29	3	
Repair List Price [\$]	\$ 82.27	\$ 307.31	\$ 377.64	
Ag. spare Part cost [\$]	\$ (2.25)	\$ (15.29)	\$ (7.05)	
Total Ag. spare Part cost [\$]	\$ (11.23)	\$ (688.06)	\$ (98.73)	\$ (798.03)
Eval rate [\$ /h]	\$ (9.57)	\$ (9.57)	\$ (9.57)	
Repair cost [\$ /h]	\$ (22.23)	\$ (22.23)	\$ (22.23)	
Total Cost Eval. [\$]	\$ (47.83)	\$ (430.50)	\$ (133.93)	\$ (612.27)
Total Cost Rep. [\$]	\$ (111.17)	\$ (1,000.50)	\$ (311.27)	\$ (1,422.93)
Repair rev. [\$]	\$ 329.08	\$ 8,911.99	\$ 1,132.92	\$ 10,373.99
Total process cost [\$]	\$ (159.00)	\$ (1,431.00)	\$ (445.20)	\$ (2,035.20)
Grand Total mfg [\$ /Unit]	\$ -	\$ -	\$ -	
Sum mfg cost [\$]	\$ -	\$ -	\$ -	
List price [\$]	\$ -	\$ -	\$ -	
Sum List Price [\$]	\$ -	\$ -	\$ -	
Opport. Cost [\$]	\$ -	\$ -	\$ -	
Combined cost of repl. [\$]	\$ -	\$ -	\$ -	

Warranty policy #3	
Cost of Opportunity	\$ -
Manufacturing Cost	\$ -
Repair Revenue	\$ 10,373.99
Evaluation Cost	\$ (612.27)
Repair Cost	\$ (1,422.93)
Spare Part Cost	\$ (798.03)
Total	\$ 7,540.76

Warranty policy #4: 4. Non-renewing free repair warranty with Canada replacements (NRFRWCR)				
Canada				
Part#	Part A	Part B	Part C	Total
# covered	0	3	0	
# not covered	1	3	0	
Repair List Price [\$]	\$ -	\$ -	\$ -	
Ag. spare Part cost [\$]	\$ (2.25)	\$ (15.29)	\$ (7.05)	
Total Ag. spare Part cost [\$]	\$ -	\$ -	\$ -	
Eval cost [\$ /h]	\$ (9.57)	\$ (9.57)	\$ (9.57)	
Repair cost [\$ /h]	\$ -	\$ -	\$ -	
Total Cost Eval. [\$]	\$ (9.57)	\$ (57.40)	\$ -	\$ (66.97)
Total Cost Rep. [\$]	\$ -	\$ -	\$ -	
Repair rev. [\$]	\$ -	\$ -	\$ -	
Total process cost [\$]	\$ -	\$ -	\$ -	
Grand Total mfg [\$ /Unit]	\$ (24.76)	\$ (257.45)	\$ (253.14)	
Sum mfg cost [\$]	\$ -	\$ (772.36)	\$ -	\$ (772.36)
List price [\$]	\$ 182.82	\$ 682.92	\$ 839.20	
Sum List Price [\$]	\$ -	\$ 2,048.76	\$ -	\$ 2,048.76
Opport. Cost [\$]	\$ -	\$ (1,276.40)	\$ -	\$ (1,276.40)
Combined cost of repl. [\$]	\$ -	\$ (2,048.76)	\$ -	
USA				
Part#	Part A	Part B	Part C	Total
# covered	3	13	0	
# not covered	11	26	-1	
Repair List Price [\$]	\$ 82.27	\$ 307.31	\$ 377.64	
Ag. spare Part cost [\$]	\$ (2.25)	\$ (15.29)	\$ (7.05)	
Total Ag. spare Part cost [\$]	\$ (31.45)	\$ (596.32)	\$ 7.05	\$ (620.72)
Eval rate [\$ /h]	\$ (9.57)	\$ (9.57)	\$ (9.57)	
Repair cost [\$ /h]	\$ (22.23)	\$ (22.23)	\$ (22.23)	
Total Cost Eval. [\$]	\$ (133.93)	\$ (373.10)	\$ 9.57	\$ (497.47)
Total Cost Rep. [\$]	\$ (311.27)	\$ (867.10)	\$ 22.23	\$ (1,156.13)
Repair rev. [\$]	\$ 904.97	\$ 7,990.06	\$ (377.64)	\$ 8,517.39
Total process cost [\$]	\$ (445.20)	\$ (1,240.20)	\$ 31.80	\$ (1,653.60)
Grand Total mfg [\$ /Unit]	\$ -	\$ -	\$ -	
Sum mfg cost [\$]	\$ -	\$ -	\$ -	
List price [\$]	\$ -	\$ -	\$ -	
Sum List Price [\$]	\$ -	\$ -	\$ -	
Opport. Cost [\$]	\$ -	\$ -	\$ -	
Combined cost of repl. [\$]	\$ -	\$ -	\$ -	

Warranty policy #4			
CANADA		USA	Combined
Cost of Opportunity	\$ (1,276.40)	\$ -	\$ (1,276.40)
Manufacturing Cost	\$ (772.36)	\$ -	\$ (772.36)
Repair Revenue	\$ -	\$ 9,369.79	\$ 9,369.79
Evaluation Cost	\$ (66.97)	\$ (545.30)	\$ (612.27)
Repair Cost	\$ -	\$ (1,267.30)	\$ (1,267.30)
Spare Part Cost	\$ -	\$ (704.04)	\$ (704.04)
Total	\$ (2,115.73)	\$ 6,853.15	\$ 4,737.42

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