Linköping University | Department of Management and Engineering

Assessment of remanufacturability

– Applying the European standard EN45553:2020 at a Swedish toner cartridge remanufacturing company

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Abstract

When moving towards a circular economy, resource efficiency in both products and processes is a topic of high relevance. The *Circular Economy Action Plan* was released by the European Union in 2020, alongside a number of standards which aim to aid shifting to greener production. This study focuses on the standard EN45553:2020: *"General method for the assessment of the ability to remanufacture energy related products"* and aims to find ways of applying the methodology presented in the standard on an industrial company case. Specifically, the study uses EN45553:2020 as a guideline for providing an assessment of the remanufacturability of the toner cartridge model CF280X, which is one of the toner cartridges that is remanufactured at the Swedish remanufacturing company called Scandi-Toner. The results suggest that this can be done by using three different types of criteria to find both critical (*must)*, supporting *(should)* and beneficial *(might)* criteria to assess how well the product meet the requirements for remanufacturing and to find areas of improvement. The study results also indicate that the assessment of remanufacturability should include two types of scores - one on whether the product is at all remanufacturable, and one on how well suited it is for remanufacturing.

Further, the study aims to find a way to generalize the methodology to also be applicable on other toner cartridge models, as well as suggesting design guidelines to make toner cartridges better suited for remanufacturing. The methodology used in the case study, and lessons learned from it, has been formulated as the *Methodology for Assessment of Remanufacturability (MAR)*. The aim with MAR is to guide manufacturing companies in assessing the remanufacturability of a toner cartridge model by using a step-by-step approach.

The study was conducted using a thorough literature study, as well as a case study at the Swedish toner cartridge remanufacturer called Scandi-Toner. The case study included an interview with an experienced worker at Scandi-Toner and an observation of the remanufacturing process. Due to the global Covid-19 pandemic during 2020, the case study was made remotely. When applying MAR, it was found that the toner cartridge model CF280X has a remanufacturability score of 90% and that there are eight redesign suggestions which would increase the remanufacturability of the cartridge model.

Keywords: *Remanufacturability, Remanufacturing, Energy-related products, Toner cartridges, CF280X, EN45553:2020.*

Preface

This report was written in connection to an advanced project course in Master of Science in Mechanical Engineering and Master of Science in Design and Product Development at the Department of Management and Engineering at Linköping University. The course covers 12 credits and is aimed as a prelude to the master thesis projects. The project was a collaboration with *Scandi-Toner Försäljning AB* in Karlstad, who provided technical expertise and assisted with guidance on the topic.

We would like to thank our supervisor Erik Sundin, professor in Sustainable Manufacturing at the Division of Environmental Technology and Management at Linköping University for invaluable support, feedback, and encouragement.

Furthermore, we would also like to thank the staff at Scandi-Toner. Special thanks to Magnus Gustavsson at Scandi-Toner for patiently answering all our questions and providing us with significant knowledge and vital information, making this project feasible.

This report covers a relatively new and somewhat novel topic in adapting a new general EU standard of remanufacturing at a Swedish remanufacturing company. Remanufacturing is highly relevant and a growing industrial sector that, in our opinion, should be utilized by more companies. Partly for its economic benefits but mainly for its contributions to circular economy. Working with such a relevant and important subject has been intriguing and educative and we are looking forward to seeing future research within the topic.

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Terminology

A1	Product attribute *Ability to be identified (CEN-CELENEC, 2020).*
A2	Product attribute *Ability to locate access points and fasteners (CEN-CELENEC, 2020).*
A3	Product attribute *Accessibility of parts (CEN-CELENEC, 2020).*
A4	Product attribute *Ability to be dissembled/assembled (CEN-CELENEC, 2020).*
A5	Product attribute *Wear and damage resistance during the remanufacturing process steps (CEN-CELENEC, 2020).*
CF280X	A toner cartridge model by HP, remanufactured at Scandi-Toner (Gustavsson, 2020). Same model properties as HP CE505X (SCC, n.d).
CF280X Process steps	The case specific remanufacturing process steps, for the toner cartridge model CF280X at Scandi-Toner. Also describes as case specific process steps.
Covid-19	The virus that caused a global pandemic in 2020. The spread of the virus limited physical gatherings and made large parts of Swedish society to work from home with help from digital tools.
Core	The product that is to be remanufactured, either a product that is in the end of its first life cycle or could have been remanufactured multiple times already (Gray and Charter, 2008).
DfRem	Design for Remanufacturing. Design for remanufacturing is a concept which originates from understanding the value of the decisions made during the product's early development phases and how it can considerably improve the remanufacturing process (Hatcher et al., 2013).
EN45553:2020	The European standard *General method for the assessment of the ability to remanufacture energy-related products,* that is studied in this project
ERP	Energy-Related Product
General criteria	Criteria which are mentioned in the EU standard EN45553:2020 *(CEN-CELENEC, 2020)* and related to specific product attributes. The general criteria are subject to modification in this study, see TC criteria.

General process steps	The general remanufacturing process steps presented in the EU standard EN45553:2020: *inspection, disassembly, cleaning, reprocessing, assembly, testing* and *storage (CEN-CELENEC, 2020).*
MAR	Methodology of Assessment of Remanufacturability, MAR. Developed within this study.
Microsoft Teams	A digital video tool used for meetings, lectures and similar where you can see and hear the person speaking (Microsoft, 2020).
OEM	Original Equipment Manufacturer. Companies that manufacture their own products in house (E Sundin and Bras, 2005).
Product attribute	An element in the assessment of the remanufacturability of the product and its parts. They are *Ability to be identified, Ability to locate access points and fasteners, Accessibility of parts, Ability to be dissembled/assembled* and *Wear and damage resistance during the remanufacturing process steps. (CEN-CELENEC, 2020)*
Remanufacturability	How well suited a product is for remanufacturing. Certain characteristics in products can have either positive or negative effect on remanufacturing. (E Sundin and Bras, 2005)
RemPro Matrix	The Remanufacturing Property Matrix, shown in EN45553:2020, correlates the product attributes to the general remanufacturing process step. The correlations illustrated in the standard is a suggestion for the remanufacturing of a generic ERP *(CEN-CELENEC, 2020)*.
Representative question	Formulated as an auxiliary step to establish the *case specific remanufacturing process* and *TC criteria*. These questions are formulated based on the case specific process in order to assess the relevance for each activity.
TC criteria	*Toner Cartridge criteria.* Also, *case specific criteria.* These criteria are case specific for the toner cartridge model CF280X modified from the general criteria in EN45553:2020 *(CEN-CELENEC, 2020)*. In the case study, these criteria were categorized into *must, should* and *might* categories, in relation to the CF280X remanufacturing process.
Toner cartridge	Also called laser toner, is a consumable component of a laser printer (Gustavsson, 2020).
Toner Hopper	One of two subassemblies of a toner cartridge. See Figure 8 for details. (SCC, n.d)
Waste bin	One of two subassemblies of a toner cartridge. See Figure 9 for details. (SCC, n.d)

1 Introduction

This introductory chapter consist of background information to the subject of remanufacturing and European standards, followed by the problem description, objective, and delimitations of the research.

1.1 Background

Products are regularly considered as waste even if parts of the product are still useful. Therefore, instead of restoring the products when used, they are discarded and replaced with newly produced products. To prevent the amount of waste and increase the environmental and economic benefits, remanufacturing can be used. (van Herpen and de Hooge, 2018)

Remanufacturing is when used products and/or parts are put into an industrial process where they are restored to the same quality as the newly produced product, which in turn creates new value for the product on the market (Amezquita et al., 1995). The remanufacturing process generally consists of seven *general process steps* which are performed either manually or by machines: *cleaning, inspection, disassembly, reprocessing, testing, storage* and *reassembly*, see Figure 1. Erik Sundin (2004) states that the order in which the steps are conducted differs between companies and products, as well as the time spent on each step. The product that is to be remanufactured is called a *core* and can be either a product that is in the end of its first life cycle or could have been remanufactured multiple times already (Gray and Charter, 2008). Depending on the condition, the number of cores needed to create a remanufactured product may vary.

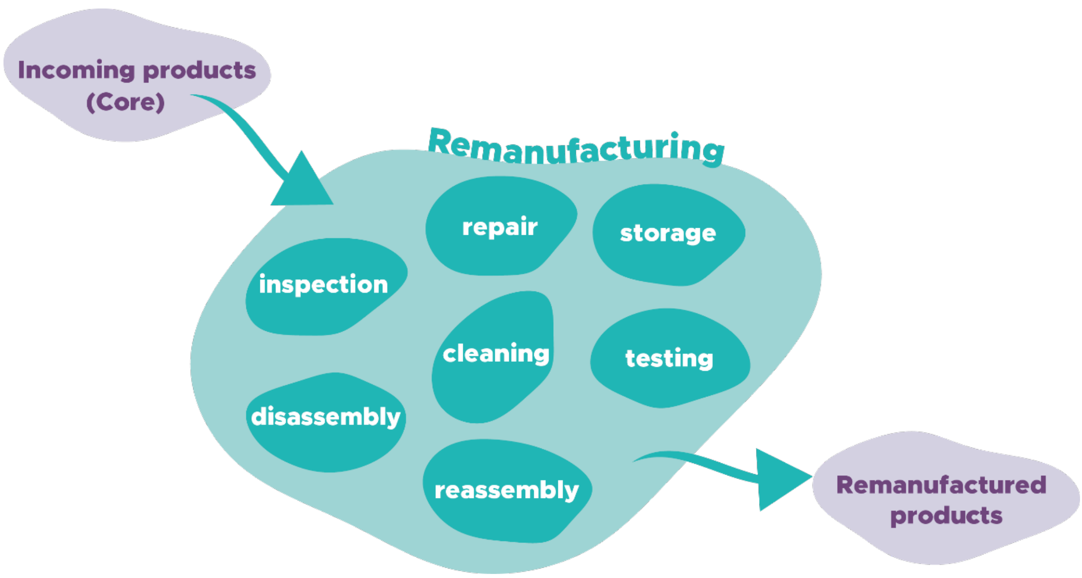

Figure 1. A generic remanufacturing process and its seven process steps. Modified from E Sundin and Bras (2005)

Not all remanufacturing is conducted by the original equipment manufacturers (OEM). Generally, remanufacturers are divided into one of three types of remanufacturing companies depending on the type of relation they have to the OEM. According to E Sundin and Bras (2005), the three types are:

Original equipment remanufacturers: OEM who remanufacture their own products in house.

Contracted remanufacturers: Companies who are hired by the OEM to remanufacture their products

Independent remanufacturers: Companies that have little or no contact with the OEM of the products and therefore must collect their cores from the customers.

Generally, when designing for the environment, a life cycle perspective is needed. It is possible to remanufacture a product that is not designed with remanufacturing in mind, however it is profitable and preferable to have them designed for this purpose. Gray and Charter (2008) states that many aspects must be considered for a product to be well suited for remanufacturing. In order to have a product with high remanufacturability one must consider these aspects in early design stages where concepts are developed and can be evaluated based on end-of-life aspects (Gray and Charter, 2008).

Design for remanufacturing (*DfRem*) is a concept which originates from understanding the value of the decisions made during the product's early development phases and how it can considerably improve the remanufacturing process (Hatcher et al., 2013). Effectiveness and efficiency of the process can therefore be greatly increased through design decisions. In addition, Gray and Charter (2008) describes *Design for Remanufacturing* as the combination of design processes where a product is designed to endure remanufacture. Improper product design is according to Rizova et al. (2020) one of the barriers for remanufacturing, which additionally affects the profitability for the product. In other words, in addition to the ecological benefits, remanufacturing also provides economic benefits. The value of a product increases with an extended lifespan and since the cost for remanufactured parts is less than for newly produced parts the remanufacturer can take part of greater profit while restoring an assembly (Amezquita et al., 1995).

Remanufacturing is part of the broader concept of Circular Economy, which represents a system shifting towards societies living in a resource efficient way in order to beat climate change (Ellen MacArthur Foundation, 2017). Circular Economy has received great attention in the European Union (EU) and in 2020 the *Circular Economy Action Plan* was released for its member states (European Union, 2020). Alongside these actions to promote Circular Economy, several standards were released to aid manufacturers to shift to greener production. One of these standards are EN45553:2020: *"General method for the assessment of the ability to remanufacture energy related products",* which aims at both helping manufacturers transitioning to remanufacturing as well as encouraging more research on the topic (CEN-CELENEC, 2020).

In EN45553:2020 a general method for assessing the remanufacturability of a product or product group, is presented. The general method is initiated by identification of the case-specific remanufacturing process for a product or product-group. This includes determining the order and the importance of the general process steps. When the remanufacturing process is specified, an identification of the link between each general process step and the product attributes, listed within the standard, is conducted (CEN-CELENEC, 2020).

A *product attribute*, mentioned in EN45553:2020, is an element in the assessment of the remanufacturability of the product and its parts. Furthermore, the attributes describe the product's ability to fulfill certain *criteria*. If a product attribute impacts the remanufacturability of the product, it should be considered in the remanufacturing process. If so, the product attribute should be specified with a list of the applicable case specific criteria (CEN-CELENEC, 2020). The product attributes are *Ability to be identified, Ability to locate access points and fasteners, Accessibility of parts, Ability to be dissembled/assembled* and *Wear and damage resistance during the remanufacturing process steps*. Each of the product attributes are described in EN45553:2020, together with suggested general criteria. The correlation between the process steps and product attributes is recognized through an evaluation of the applicability of the correlation and then establishing criteria for the relevant product attributes (CEN-CELENEC, 2020).

1.2 Problem description

The European standard EN45553:2020 contains a general methodology for assessing remanufacturability that is applicable to a large range of energy-related products and thus needs to be specified for each product or product group.

Toner cartridges is one energy-related product which is often remanufactured, but where a specific strategy for evaluating remanufacturability still is missing. Remanufacturing of toner cartridges is most often conducted by independent remanufacturers, an example of one being Scandi-Toner in Karlstad, Sweden. (G Johansson et al., 2019)

1.3 Objective

The aim for this project is to develop a scoring method for assessing the remanufacturability of toner cartridges within the requirements set up in the European standard EN45553:2020. To meet the aim of this project, four research questions are to be answered.

The first research question originates from the problem that a specific strategy for evaluation of remanufacturability of toner cartridges does not exist today. Therefore, the aim is to find ways to apply the general methodology from the EU standard EN45553:2020 to the product category. For this to be done, research on the topic of remanufacturability, toner cartridges, the remanufacturing market of stated product as well as on general scoring method development will be conducted. Alongside this, a case study will also be performed. The first research question is formulated as follows:

> **RQ1:** *How can the general assessment methodology in EU standard EN45553:2020 be applied to the remanufacturing of toner cartridge CF280X?*

As a result of the case study, a score of the remanufacturability of the toner cartridge model is wanted for comparison with other models and for finding improvement areas. Research on how these calculations can be conducted is covered by the second research question:

> **RQ2***: How can a scoring method for assessing remanufacturability of toner cartridge CF280X be developed?*

Since the general EN45553:2020 was released for the first time in summer 2020 there is yet to be studies conducted on how to apply its methodology to products and product groups. After a scoring method has been developed for the toner cartridge CF280X specifically, the project will explore the possibilities of expanding the method further to other toner cartridge models. With this in mind, the third research question is formulated as follows:

RQ3: *With potential modifications, how can the assessment method be applied to similar toner cartridges?*

Within the work with RQ1 and RQ3, it is likely that it will be found that some parts of the current toner cartridges complicate the possibility of remanufacturing. In the fourth and final research question, the aim is to identify these design flaws and formulate guidelines for redesigning toner cartridges to better enable remanufacturing. Therefore, the fourth research question is formulated as follows:

RQ4: *Which design guidelines are beneficial to implement, to better enable remanufacturing of toner cartridges?*

1.4 Delimitations

The only product group considered in the case study performed in this research was toner cartridges specifically remanufactured by the Swedish remanufacturing company Scandi-Toner. The company was used for empirical studies within the case study.

Only technical criteria for remanufacturing of a product were accounted for. Non-technical criteria like economic factors, supply and demand or ethical factors was not included in the assessment of remanufacturability. This is also the focus of EN45553:2020.

The only type of toner cartridges considered in this project were mono toner cartridges (only prints in black and white). Color toner cartridges were excluded.

An optimal user experience of the developed method is not prioritized in the scope of the project. That the presented results are usable is prioritized.

2 Methodology

The methodology for this research is described below. Subchapter 2.1 gives an overall view of the work process and content of this study. In subchapter 2.2-2.4 descriptions and aim of the activities, presented in 2.1 and conducted in this study, can be found. Furthermore, subchapter 2.5 describes the research strategy and how the research questions will be answered.

2.1 Work process

The work process of the research is presented in figure 2, below.

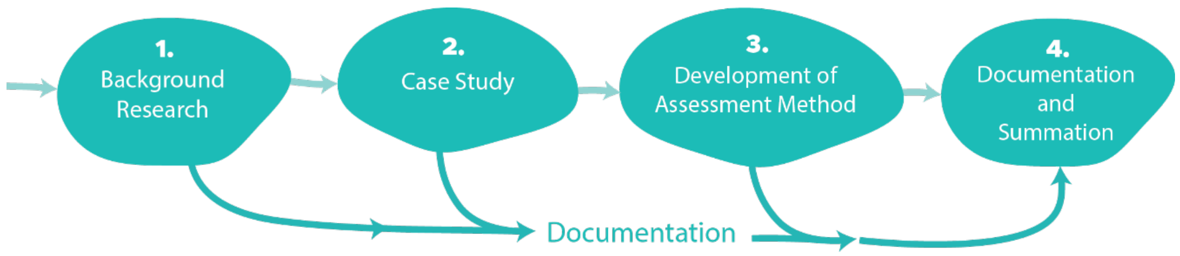

Figure 2. Work process

The steps, illustrated in figure 2, individually consists of several activities and were conducted with several iterations within each step. These activities were:

1. **Background Research**
    - Literature Study
    - Case Specific Theory
2. **Case Study**
    - Interviews and observations (data collection)
    - Assessing the remanufacturability of CF280X
    - Development of scoring method
    - Calculation of score for toner cartridge CF280X
3. **Development of Assessment Method**
    - Generalizing the case study methodology and data output
    - Creation of MAR – Methodology of Assessment of Remanufacturability
4. **Documentation and Summation**
    - Analysis and conclusions
    - Completing report for project closure and future research

Further, these steps are thoroughly described in the following subchapters.

2.2 Background research

The background research was conducted with the goal to obtain knowledge and understanding of essential topics related to the subject of this report that were needed to answer the research questions. This chapter describes the aim of the background research and how it was conducted. The research was made through searching the databases UniSearch (Linköping University library) and Google Scholar. Topics researched, with corresponding searched key words, are listed below.

2.2.1 Literature study

The aim with the literature study was to gain knowledge about topics relevant to remanufacturing and for conducting interviews and observations.

Remanufacturing

The research was focused on gaining knowledge on the general proceedings and process steps within remanufacturing, as well as understanding the motivations within the industry. The research also covered background information on why remanufacturing was developed and how it has evolved in recent years. The literature mainly consisted of articles written ten years ago or more, however, no major changes has been made in the toner cartridge industry during this time. The information collected from the older references was verified and updated during the case study to ensure credibility.

[keywords: *remanufacturing, remanufacturability, design for remanufacturing, design for environment, sustainable manufacture, circular design, sustainable manufacturing, Remanufacturable, Eco-design*]

Interviews and observations

The need for research within this area appeared when realizing a company visit was needed for collection of data. How to prepare for, conduct data collection sessions and analyze the data seemed necessary to assure the quality of the data and time efficiency during the company visit. In case of cancelled company visit, preparations were also made to ensure quality data collection by using digital tools as well.

[keywords: *scientific interviews, conducting interviews, user observations, participant observation, conducting digital interviews*]

2.2.2 Case specific theory

To gain knowledge about the company and the product prior to the case study, case specific theory was collected. This included finding previous work and studies performed at the company in question and check their current production and capabilities. Which product models the company was remanufacturing at the time was interesting and used as a verification to the older references found in the search for case theory. The results of the case theory can be found in chapter 4. Case specific theory.

Development of assessment method

The research on method development aimed to find structured ways to efficiently conduct method development. With remanufacturability in mind, this part of the research aimed to find previous work that had used methods that could be applied within the scope of this project.

This was done to support the analysis of the standard, as well as to clarify and explicate the information in the standard, due to its general nature. Some research was done on quantifying the assessment of remanufacturability.

[keywords: *assessment method, remanufacturability assessment quantifying remanufacturability, implementation of technical standards, quantifying remanufacturability*]

Toner cartridges
The aim of this part of the research was to understand the product which was to be analyzed. The research included what a toner cartridge is, its use and potential reuse, the general remanufacturing steps of the cartridge as well as information about the toner printer market. Difficulties regarding remanufacturing of toner cartridges were also included here.

[keywords: *toner cartridge, toner cartridge market, toner cartridge manufacturers, toner cartridge manufacturing, Design for remanufacturing AND toner cartridge, Remanufacture AND toner cartridge, Remanufacturability AND toner cartridge, Remanufacturability assessment*]

2.3 Case study

With the aim to investigate how to assess the remanufacturability of a specific toner cartridge model according to EN45553:2020, a case study was conducted as part of the research. To fulfill the aim, the case study included the gathering of complementary data about the remanufacturing process of toner cartridges as well as Scandi-Toner´s toner cartridges in general. Furthermore, the case study involved the development of a method for assessing remanufacturability and calculation of a remanufacturability score for one specific toner cartridge – with the aid of the literature study.

The researchers were supposed to visit Scandi-Toner´s remanufacturing facility of toner cartridges with the purpose to conduct interviews with key figures as well as observe the work process. However, because of Covid-19 the interviews and observations were performed in a digital setting instead.

The case study was initiated by interviews and observations which were conducted digitally with the aid of videos and the digital meeting tool Microsoft Teams. According to EN45553:2020, the first step in the assessment of remanufacturability should be identification of the remanufacturing process for a specific product or product group. This included identification of the order of the general remanufacturing steps and the determination of the importance of each step. The mapping and gathering of information were compiled with the aid of interviews with an employee at Scandi-Toner together with observations of the remanufacture company´s production. In subchapter 2.3.1 *Interviews and observations* the aim, preparations and the conduction of the interview are thoroughly described, as well as for the following observations in the same subchapter.

The data collected in both the interview and the observations were analyzed and compared to the theory gathered in the literature study. The gathered information was used to calculate a score of the remanufacturability of the toner cartridge model CF280X at Scandi-Toner. How this was conducted was described in subchapter 2.3.1.

2.3.1 Interviews and observations

The aim of the interviews and observation was to investigate and map the process steps in the remanufacturing process for one toner cartridge model. Therefore, the first information gathered within the interview was the name of a toner cartridge model suited to represent toner cartridges in general: CF280X.

To acquire information and gain as much understanding as possible during the case study, organized data collection was needed. Interviews are made to receive qualitative data for research when the aim is to collect "facts" and information about processes and behaviors (Rowley, 2012). When desiring open answers to prepared questions with the possibility for the interviewer to ask follow-up questions, semi-structured interviews are the best option (Wikberg Nilsson et al., 2015). With the goal of the interviewee feeling comfortable to share details from the manufacturing process, semi-structured interviews seemed to be suitable for this research.

The interview and preparations were conducted according to these 6 stages of performing interviews by van Boeijen et al. (2020):

1. Prepare an interview guide and make a pilot interview. Formulation of purpose and topic.
2. Decide how many interviews are needed and contact the interviewees.
3. Explain the goal to the interviewees and how their input will be treated.
4. Carry out the interviews.
5. Prepare material for analysis.
6. Analyze and write report basis.

In the case of this study, an extra step was added between step 5 and 6 where the need for a follow-up interview and complimentary video material was needed to move on to the analysis and report.

Even though performing interviews face-to-face is beneficial for interpretation of answers (Wikberg Nilsson et al., 2015), the circumstances with Covid-19 forced the data collection to be performed in a digital setting instead. The interviews were held through a video-based phone call, using the tool Microsoft Teams, where the interviewer could see the responder's face while asking the questions.

Since the outcome of interviews are depending on the accuracy and relevance of the questions asked, observations can be a good addition to see potential problems the interviewer did not think about asking and to discover non-verbal expressions of feeling or discomfort of the participants (Kawulich, 2012). This is the reason observations were used in the research, sometimes when performing a manufacturing step an experienced operator is not aware of details or steps they are making because of the routine of the step. Observations is a method used for collecting data where you watch a process or person in a setting you want to gain understanding about (Kawulich, 2012; van Boeijen et al., 2020). However, one thing to keep in mind is that people who know they are being observed, might behave differently than they would normally (van Boeijen et al., 2020). For this research, observations were used as a complimentary tool to interviews to enable collection of both verbal and non-verbal data about the product and process studied in the case study.

Because of Covid-19 regulations, the planned observations for this study were made digitally instead of physically. Videos of the case specific manufacturing process steps were filmed by the manufacturer and an operator commented on every step. Follow up questions on clarification of the video material were answered afterwards. Videos are already a commonly used tool in observations to aid the processing of the data (Kawulich, 2012), which is why this felt like an acceptable alternative to physical observations. A further description of the interview and observations could be found in subchapter 5.1 *Data Collection* within the Case study.

2.3.2 Scoring of Remanufacturability

The aim with the scoring of remanufacturability within the case study was to get a numeral score of how remanufacturable a toner cartridge model was. The specific product used in the case study was the toner cartridge model CF280X, described in subchapter 4.2.1. *CF280X* was identified within the interview and confirmed by the literature as being a representative and common toner cartridge model for remanufacturing.

Initially, correlations were identified on how the collected data from interviews and observations correspond with the background research. The deepened understanding of the technical function of a toner cartridge were compared to the general remanufacturing steps described in EN45553:2020. The aim with this was to see how well the literature, including EN45553:2020, corresponded with the studied case specific remanufacturing process.

In correlation with the first suggested step in EN45553:2020, the *CF280X process steps* conducted when remanufacturing the toner cartridge CF280X was established. To explicate the identified case specific process steps, each step was presented as a list of activities. These activities were then compared to the general criteria for each product attribute found in EN45553:2020. The applicable criteria were then translated into *representative questions* that were answered to evaluate its relevance of each activity.

The representative questions were then reformulated into new *TC criteria* (*toner cartridge criteria)* determining the remanufacturability for each CF280X process step for the specific toner cartridge. The total list of TC criteria was then assessed and revised multiple times to assure the validity of the model. Each criterion was then assessed and categorized in accordance with the different product attributes. These steps were conducted to affirm that the formulated criteria reflect the case specific remanufacturing process in a comprehensive fashion. Furthermore, *must*, *should*, and *might* labels were used to categorize the TC criteria. This was to explicate the importance of criteria, in relation to each other and regarding remanufacturability in general. The toner cartridge CF280X was then evaluated in relation to its fulfilment of each TC criterion – giving it a binary score of YES or NO.

When calculating a score of remanufacturability using an excel sheet, the criteria *must*, *should* and *might* had to be weighed in relation to each other. All the fulfilled TC criteria were given the score 1 and if not fulfilled, 0. The relative importance of the criterion categories was analyzed, and the *must*, *should* and *might* were weighed in relation to each other, using one weight coefficient for each criteria type. Furthermore, another type of weight coefficient was set for the case specific process steps. The summation of the score of the TC criteria was then made for each criteria category, one for *must*, one for *should* and one for *might* criteria. If the *must* criteria score does not reach 100% the model is not remanufacturable at all. The score for the *should* and *might* criteria show where the largest design improvement areas can be found. The three categories were then added together to form the final and total score for CF280X and display its remanufacturability. Further results were compiled, relating the weight of different types of TC criteria, comparing the general process steps to the product attributes.

2.4 Development of assessment method

With the aim to broaden the scope of the assessment method used for the case study, the process of assessing the remanufacturability for CF280X was adapted to fit other models of toner cartridges. Furthermore, a general method for how one could repeat the assessment and develop a corresponding model for other toner cartridges and processes was formulated. This method was called *Methodology for Assessment of Remanufacturability (MAR)*.

Before the development of MAR was initiated, the target group for the method was chosen. This was defined through discussions of who the possible users were, where the method could have the most impact, and what the goal of the project was. The chosen target group later influenced the formulation of the process steps within MAR.

The development of MAR was initialized by summarizing the methodology within the case study, and then generalizing the collected data and the produced results. To explicate the method used for assessing the remanufacturability of CF280X, each step in the case study was briefly described in a general fashion. The essential part of developing MAR was the method formulation – each step in the process was described with the aim of the user being able to conduct future assessments of remanufacturability, with unambiguous methodology. Furthermore, efforts were made to formulate and use a language suited for the intended users of MAR.

2.5 Research strategy

The research strategy for the project consists of several methodologies such as literature study (shown in chapter 3 and 4), data collection and case study (chapter 5) and development of assessment method (chapter 1). These methods aim to answer the research questions and are contributing in different ways to respond to each of the individual questions.

The first research question, applying the general methodology in EN45553:2020 to a specific toner cartridge model, was processed using the literature study and the case study. The literature study provided with background knowledge about the subject needed to answer RQ1, and the case study, aimed to assess the remanufacturability by adding new findings on and enabling the implementation of the general methodology. The second research question aimed to calculate a score for the remanufacturability of CF280X with the help of the case study and the results of RQ1, where the assessment of the case is quantifies with the calculation of a score.

The third research question, with the aim to broadening the scope of the proposed assessment method to be utilized for other toner models, was to be answered with information gathered in all three methodologies – the literature study, case study and development of the scoring method. Furthermore, research question four is also answered with data from all three categories, where design upgrades for the facilitation of remanufacturing are investigated.

The correlation between the methodologies and answering the research questions is presented in Table 1.

Table 1. Research questions and the corresponding methods within the study.

RQs / Methodology	*Literature Study*	*Case Study*	*Development of assessment method (MAR)*
RQ1	•	•	
RQ2		•	
RQ3	•	•	•
RQ4	•	•	•

3 Theoretical framework

Theoretical framework compiles the literature study and important knowledge for answering the research questions. Information regarding remanufacturing in general is presented, also covering remanufacturability and Design for Remanufacturing.

3.1 Remanufacturing

Remanufacturing is the process of industrially restoring already used products, so that they can be used again with the same, or better, quality (Erik Sundin, 2004). The process is generally done in an industrial setting, where several pre-set sub-processes are systematically conducted either manually or by machines. This could be seen as one of the core concepts of circular design, as its main focus is to use technical nutrients and circulate them within the system while having them be restorative and regenerative by design (Gray and Charter, 2008).

Every remanufacturing process consists of seven process steps: cleaning, inspection, disassembly, reprocessing, testing, storage, and reassembly (as seen in Figure 1). However, in what order they are conducted is arbitrary and dependent on the specific product and company policy (E Sundin and Bras, 2005). For example, for some products it is more cost-effective to disassemble the core before cleaning and inspection. For other products, it may be beneficial to clean and inspect the products before disassembling them (Erik Sundin, 2004). The sub-processes themselves are rather self-explanatory but may differ slightly from product to product. Below follows a brief explanation of each sub-process, as found by Bras and Hammond (1996). Note that the sub-processes are not listed in the order of execution.

- **Cleaning**: The core is cleaned and potentially disinfected. May not be necessary for all products.
- **Inspection**: The core is inspected and deemed either suitable or non-suitable for remanufacturing.
- **Disassembly**: The core is dismantled and separated into smaller parts suitable for remanufacturing.
- **Reprocessing**: Changes and/or updates that are necessary for remanufacturing are conducted.
- **Testing**: Tests and quality checks are conducted throughout the process to ensure high quality of the remanufactured parts or products.
- **Reassembly**: The remanufactured parts are either put together with other used/remanufactured parts or with new parts to form a remanufactured product.
- **Storage**: The remanufactured part or product is put into storage for a shorter or longer period before put to use.

In the following sections a background to remanufacturing is given. This is conducted through a literature study assembling facts considering the reasons to remanufacture, how it could be measured and guidelines to how it is accomplished successfully.

3.1.1 Why remanufacture?

Environmentally benign products as well as processes are in more demand now than ever and waste management alongside landfill space is one of the most urgent environmental problems in high income countries. The escalating environmental problems pushes for change in legislation and increases pressure from European governments on manufacturers. Global manufacturers are therefore spurred to improve the involvement of post life considerations in their product design processes. (Amezquita et al., 1995; Hatcher et al., 2013; G. Johansson et al., 2019)

Understanding the factors driving the market for remanufacturing can contribute to insights that consider which characteristic in products that are important for the ability to be remanufactured. Amezquita et al. (1995) defines economics, legislation, and ecology as the three primary factors that drives the development and growth of remanufacturing.

The addressed environmental problems considering waste from manufacturing increases the interest of environmental benign processes and products. Since remanufacturing provides ecological benefits, such as reducing the amount of waste and energy required in the manufacturing process, the manufacturers interest enhances for the process as it can be considered as less harmful for the environment than current production. (Amezquita et al., 1995; Bras and Hammond, 1996; Gray and Charter, 2008)

In addition to the ecological benefits, remanufacturing also provides economic benefits. Product remanufacturing can contribute to a significant reduction of the impact on the environment as well as, opposed to recycling, preserving the economic value through retaining the products geometrical form (Bras and Hammond, 1996). In general, remanufacturing contributes to more economic profits compared to other reclamation processes such as recycling. Furthermore, the cost for remanufactured parts is considerably less than for newly produced products which allows the remanufacturer to take part of a greater profit while restoring an assembly (Amezquita et al., 1995).

There are numerous different reasons to remanufacture. In addition to those mentioned above, G. Johansson et al. (2019) state that reasons for remanufacturing vary depending on the products and the company. The European Remanufacturing Network (ERN) highlight additional incentives that commonly motivate companies to remanufacture. Those are economics, cost savings, access to cores, reduced lead times, alternative business models, reduced risk of resource insecurity and environmental legislation. (G. Johansson et al., 2019)

According to Nasr and Thurston (2006), one essential step towards a more sustainable industrial society is closing the loop on the material flows connected to product or service delivery. This need originates from the increasing standard of living in combination with the unsustainable quantities of consumption and use of non-renewable material sources, and this is where remanufacturing can be a valuable part of a product life-cycle solution. The loop for product system is illustrated in Figure 2 where the consumption and disposal of products can be seen. However, the figure also integrates the three alternative aids to close the loop and contribute to a more sustainable society; *recycle, remanufacture,* and *reuse*.

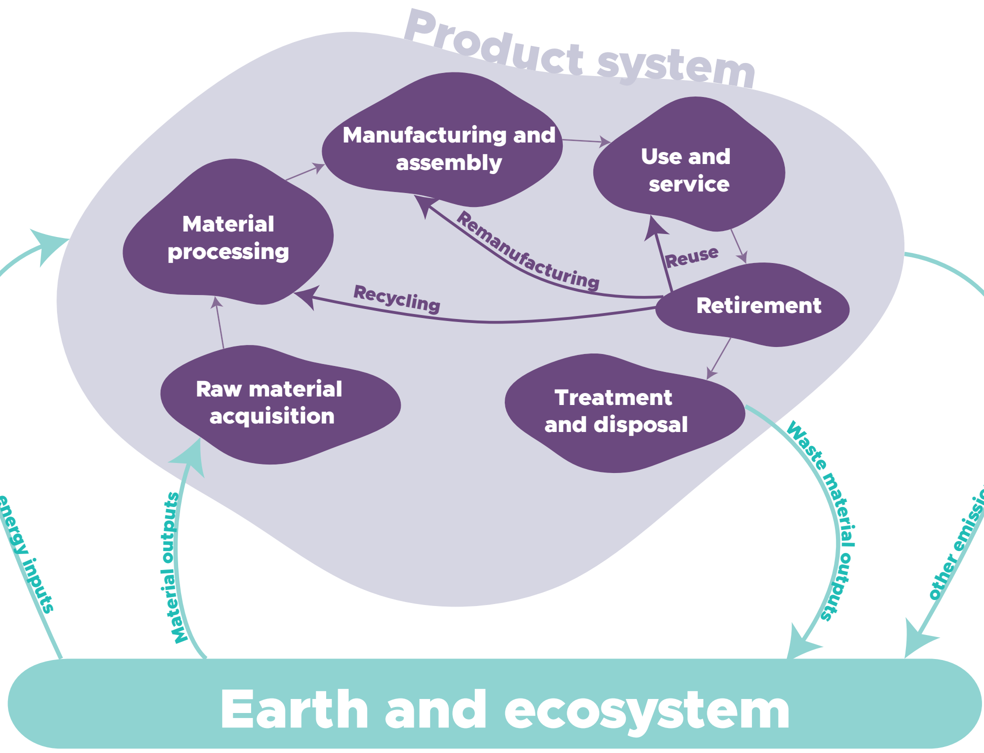

Figure 2. The closed loop of product system and material flows. Modified from Nasr and Thurston (2006)

3.2 Remanufacturability

The remanufacturability determines if a used product can be remanufactured or not (Du et al., 2011), and according to Gray and Charter (2008) there are certain properties of products that make them better suited for remanufacturing than others. Furthermore, certain characteristics in products can have either positive or negative effect on remanufacturing and can be used to understand what makes a product easier to remanufacture. Examples of factors that are common in successful products in the field and therefore can be considered beneficial for remanufacturing are (Gray and Charter, 2008):

- **Slow pace of technology evolution:** Products that changes slowly are easier and more profitable to remanufacture.
- **Durability:** The ability to withstand multiple life cycles is important for the product's remanufacturability.
- **Possibility to either reverse engineer or disassemble**

Corresponding to what Gray and Charter (2008) article conveys, any product that can be manufactured can also, in theory, be remanufactured. However, some product´s detailed design and business models can entail a more profitable remanufacturing than others, and by using design for remanufacturing both can be optimized (Nasr and Thurston, 2006).

However, products that are remanufacturable can be characterized as products with long-wearing materials and with parts containing a high value. For a product to be remanufacturable it is important that it is worth investing in and that it is durable enough to withstand multiple lifecycles. (Hatcher et al., 2013)

In addition, Ijomah et al. (2007) conducted a case study resulting in the identification of design features affecting a product's remanufacturability including the features *assembly type, product complexity, materials* and *design cycle*. These were compiled in Table 2 together with the identified problems, a graded severity of impact and comments such as explanation or reasons.

Table 2. Design features affecting product remanufacturability, Ijomah et al. (2007).

Design features	Problems identified	Severity of impact	Comments, e.g., Reasons, explanations, etc.
Assembly type		1-4	Assembly type may hinder disassembly, an essential and initial activity to the point that remanufacture is impossible.
	Screws	1	Time consuming but generally would not make remanufacturing impossible.
	Rivets	2	Time consuming but generally would not make remanufacturing impossible.
	Welding	3-4	Difficult/impossible to disassemble depending on weld type
	Strong adhesive (e.g., epoxy)	4	Very strong adhesive can prohibit disassembly.
Product complexity		3	Product complexity may necessitate increased complexity, may require more types of testing, more expensive testing, thus increasing resource used in terms of skills and time.
	Numerous components	2	Numerous components require more resource for testing and remanufacture.
	Product dimension	2	Size and weight of product can be detrimental e.g. by making access to damaged components difficult
	Internal component arrangement	2-3	May lead to wear because of friction between parts. May make remanufacturing more complex and expensive because of difficulty in accessing damaged parts. Caused by ineffective communication between end-user, remanufacturer, manufacturers, and designers.
	Coatings	2	Unnecessary/ineffective coating can inhibit remanufacturing and may even be detrimental in the long run, e.g., flaking Teflon coating may leave debris that may damage components.
Materials		4	Non-durable materials cannot be remanufactured. Banned materials deters remanufacture.
Design cycle		3	Resource expended to keep pace with modernity.
Scale showing severity of problem's impact on remanufacturing: 			

Furthermore, there is research conducted on developing a method to measure remanufacturability. According to a preliminary version of EN45553:2020, the product´s type is affecting the ability to be remanufactured and which steps that are to be used for the process. In Table 3 below is an assessment of the ability to remanufacture an energy-related product, created by Erik Sundin (2019) also the supervisor for this project, as an example of how a simple scoring method could look like. The score is formed as 1 = "*very low*", 5 = "*Very high*".

Table 3. Simple scoring method - Remanufacturability made by Erik Sundin (project supervisor), prEN45553:2020 (2019)

Score / Attribute	**1**	**2**	**3**	**4**	**5**
Ease of locating access points and fasteners					x
Ease of verification and testing				x	
Ease of access			x		
Ease of dis-/reassemble				x	
Wear Resistance		x			
Total score:	**18 points**				

Moreover, according to Amezquita et al. (1995) the design of the products and the early stages of design is the part where the larges enhancement of remanufacturability can be done. Design for remanufacturing is therefore an important aspect of remanufacturability and the concept was described further in the next subchapter.

3.3 Design for remanufacturing

Design for remanufacturing, also referred to as *DfRem*, is a concept which originates from understanding the value of the decisions made during the product's development process and its considerably improvement of the remanufacturing process. Moreover, effectiveness and efficiency in the remanufacturing process can considerably be increased through design decisions. (Hatcher et al., 2013)

In addition, (Gray and Charter, 2008) describes *Design for Remanufacturing* as the combination of design processes whereby a product is designed to facilitate remanufacture. Furthermore, improper product design is according to Rizova et al. (2020) one of the barriers for remanufacturing, which additionally affects the profitability for the product.

In order to maximize the products remanufacturability and overall profit through the life-cycle, OEM's designers must consider the end-of-life stages and the pre-life when taking design decisions in the product development process (Rizova et al., 2020). In addition, Nasr and Thurston (2006) state that to achieve the full societal benefits of remanufacturing, *DfRem* must become an integral part of the product development process. This includes *DfRem* on a product strategy, detailed product, and manufacturing engineering level (Nasr and Thurston, 2006).

According to Nasr and Thurston (2006), there are two levels of *Design for Remanufacturing*. The first one is the product strategy level regarding sales, marketing, service support, and reverse logistic concerns. The second one is the detailed product and manufacturing engineering level. (Nasr and Thurston, 2006)

Moreover, Nasr and Thurston (2006) summit a list of general *DfRem* technologies which are connected to common issues regarding the product's detailed design. These are (Nasr and Thurston, 2006):

- Design for disassembly (and separation)
- Design for multiple life cycles (product reliability, durability, restoration, and cleaning)
- Modular design: Functional clusters of components with similar technical (durability) and market life (technology change rate)
- Product support for take-back decisions (embedded condition or usage monitoring)

3.3.1 Guidelines for design for remanufacturing

There are guidelines for design for remanufacturing produced to improve the process through different methods and through considering various aspects while developing new products. Below are different guidelines and methods to improve remanufacturing mentioned.

According to Ijomah et al. (2007) remanufacturability specific guidelines can enhance the remanufacturability for a product as well as using *Design-for-X (DfX)*, either in combination or individually, given remanufacture priorities are considered. The umbrella term "*Design-for-X*" includes several design methodologies and philosophies addressing the gap in knowledge of designers concerning important life-cycle areas, whereas the X represent the aim of the method. Moreover, methods within DfX is striving to include environmental aspects into design process and product development and an example is design-for-disassembly which enhance the remanufacturability. (Ijomah et al., 2007)

In addition to the strategies above, Ijomah et al. (2007) compiled examples of high-level guidelines correlating to specific steps in the remanufacturing process. Examples of these guidelines could be seen in Table 4, where each process activity was combined with guidelines correlating to the product's material, assembly technique and structure. The complete list of guidelines mentioned by Ijomah et al. (2007) was compiled in Table 15 and can be found in Appendix 1 – Tables from the Literature study.

Table 4. Examples of remanufacturing guidelines created by Ijomah et al. (2007).

Process activities	**Product/design characteristics**		
	Material	**Assembly technique**	**Product structure**
Disassemble product	For components destined for reuse ensure that their materials are sufficiently durable to survive disassembly.	Use assembly methods that allow disassembly without damage to components.	Arrange components for ease of disassembly
			Reduce the total number of parts.
Clean components	Use material that would survive cleaning process e.g., ensure that material melting point is higher than clean process temperature	Use assembly methods that allow disassembly at least to the point that internal components can be accessed for cleaning.	Arrange components so that all can be accessed for effective cleaning
			Ensure product surfaces are smooth and wear resistant.
	Limit the number of material types per part.		Reduce/eliminate redundant parts.
Remanufacture components	Use materials that are at least durable enough to survive to refurbishment process.	Use assembly methods that would allow disassembly at least to the point that internal components and subsystems requiring.	Standardize parts.
			Structure for ease in determining component condition
Assemble product	Limit the number of different materials.	Identify components requiring similar assembly tools and techniques.	Standardize parts.

The authors of ERN design landscape report (2016) encapsulate design guidelines for remanufacturing found in literature. New Product Development (NPD) activities, can be driven by design guidelines that can aid designers to accomplish the anticipated goal and simultaneously integrate good design procedures easily during the product development process (ERN, 2016).

The guidelines could for example include the following strategies, stated by ERN (2016); *DfRem, Functional integration, Light-weighting/Right-weighting* and *Material substitution*. These strategies are meant to, in different ways, contribute to better design and help designers reach their anticipated goal with the product – such as designing products more suitable for remanufacturing.

Others have created more direct guidelines, meant to be used during NPD, and are aspects to consider while aiming to design products adapted for remanufacturing. Amezquita et al. (1995) presents the following design guidelines and design aspects which should be considered when designing for remanufacturing:

- *Ease of identification*: The inspection is a vital step in the process to identify errors and parts in need to be replaced within the product. Thus, this step does not add any value it is important to spend as little time as possible by making it easier to identify damage and defects on the toner cartridge.
- *Ease of disassembly*: An important step in the remanufacturing process is the ability to disassemble the product, preferably without damaging any parts. As for the *ease of identification* this is a non-valuable adding step and reducing the time spent during this phase, by making it easier, is important.
- *Ease of cleaning*: Surfaces in need of cleaning should be accessible and withstand wear as well as accumulating residue from cleaning. Therefore, the designer must have knowledge of what methods that may be used for cleaning and which parts that need to be easy to access. This should be considered during the design process.
- *Ease of part replacement*: To prevent damage during replacement of parts the wear resistant parts should be easy to replace and simultaneously reduce the time spent in this part of the process.
- *Ease of reassembly:* Spending less time in this step is important since remanufactured products get reassembled multiple times.
- *Reusable components:* As the number of reusable parts in a product elevates the more profitable the product is to remanufacture – particularly for parts that are expensive to manufacture and replace.
- *Standardization*:
    - <u>Modular components:</u> Making the design modular helps the assembly and disassembly of the products parts and simultaneously reduces the time to do so, which are beneficial for remanufacturing.

- Fasteners: Standardization to reduce the number of different fastenings makes the product less complex with respect to assembly and disassembly and the material handling process.

- Interfaces: Standardization of the component's interfaces entail less parts needed to manufacture a larger range of similar products. This is beneficial for remanufacturing thus it gains economics of scale.

4 Case specific theory

This chapter contains theory specified to remanufacturing of toner cartridges and knowledge that was needed to complete the case study. Also, data from the studied company Scandi-Toner is presented.

4.1 Methods for assessment of remanufacturability

Within this section, some already existing methods to determine remanufacturability are mentioned.

There are several types and classifications for technical standards (European Commission, 2016). The standard EN45553:2020 - *General method for the assessment of the ability to remanufacture energy-related products* has been developed to potentially apply to any ERP. Therefore, the standard has a general nature and describes and defines fundamental principles, concepts, and terminology. It is suggested that it is used by e.g. technical committees when producing generic publications on specific products or product-groups. (CEN-CELENEC, 2020). The suggested general methodology for assessing the remanufacturability of a product or product group, as presented in EN45553:2020 is:

1. Identification of remanufacturing process for specific product or product-group
    a. Identification of the order of the remanufacturing process steps
    b. Determination of the importance of each step
2. Identification of the link between each process step and the product attributes.
    c. Evaluation of the applicability of the link between the process steps and product attributes.
    d. Establishing criteria for the relevant product attributes
3. Documentation in accordance with EN45553:2020

E Sundin and Bras (2005) examined the general steps in a remanufacturing process and developed a matrix from these steps. The Remanufacturing property matrix, also named *RemPro Matrix*. As shown in Table 5, the RemPro Matrix consists of the general process steps from the generic remanufacturing process and illustrates which of the product attributes that are relevant for the different steps in the remanufacturing process. The RemPro Matrix, seen in EN45553:2020, osught to be used as a method to identify relevant properties/attributes for each step. (CEN-CELENEC, 2020; E Sundin and Bras, 2005)

Table 5. The RemPro matrix as described in EN45553:2020 (CEN-CELENEC, 2020) based from Sundin & Bras (2005).

Product Attribute	Remanufacturing Process Steps						
	Inspection	**Disassembly**	**Cleaning**	**Reprocessing**	**Assembly**	**Testing**	**Storage**
Ability to be identified	X					X	X
Ability to locate access points and fasteners		X			X		
Accessibility of parts		X	X	X	X	X	
Ability to be disassembled/assembled		X			X		X
Wear and damage resistance during the remanufacturing process steps	X	X	X	X	X	X	X

A product attribute is an element in the assessment of the remanufacturability of the product and its parts and describes the product's ability to fulfill certain criteria. If a product attribute impacts the remanufacturability of the product, it should be considered in the remanufacturing process. If so, the product attribute should be specified with a list of the applicable criteria (CEN-CELENEC, 2020). The following list describes the evaluation of the product attributes in EN45553:2020.

- *Ability to be identified* refers to the ease of identification.
- *Ability to locate access points and fasteners* refers to the ease of localizing key elements for disassembly and assembly.
- *Accessibility of parts* refers to the ease of access to product parts.
- *Ability to be dissembled/assembled* refers to the ease of separation and assembly of product parts
- *Wear and damage resistance during the remanufacturing process steps* refers to the product's ability to withstand all necessary treatment during the remanufacturing process.

When creating a method to assess remanufacturability of a product, the most relevant criteria of the product attributes are to be selected. An assessment of the attributes should be done in reference to the chosen criteria. The overall remanufacturability of a product is then decided as the combination of the product attribute assessments (CEN-CELENEC, 2020). An important note is that all necessary remanufacturing process steps needs to be executed for a product to be remanufactured.

4.2 Toner cartridges

Within chapter 4.2, information about toner cartridges is presented. In subchapter 4.2.1 toner cartridges are explained and the components within the toner cartridge displayed. Moreover, the printer toner market is briefly summed in subchapter 0.

4.2.1 What is a toner?

A toner cartridge is the disposable consumable part of a laser printer. When the printer is out of toner, the cartridge with toner can be replaced with a new one (Canon, 2020). The actual toner powder is a plastic/iron blend that is manufactured to stick to the paper when heated (Hermansson, 2006). The powder sticks easily to other surfaces and can be a problem when disassembling and cleaning the toner cartridge. This powder also come in many different colors when used in a printer for color laser printing (Canon, 2020). Some of the largest manufacturers of toner cartridges are Brother, Canon, Epson, Hawlett Packard, Lexmark, Oki and Samsung (Scandi-Toner, n.d).

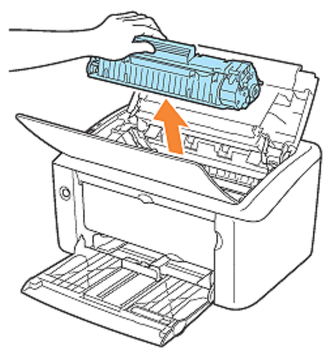

Figure 4: Toner cartridge removed from printer (Canon, 2020)

A toner cartridge has several critical components that gets worn out during use of the printer. The parts that are often removed or replaced from the cartridge when remanufactured, are (Hermansson, 2006; SCC, n.d):

- Doctor blade
- Mag roller
- Bushings
- OPC drum
- PCR roller
- Wiper blade

The OPC-drum always has the same dimensions since it is adapted for A4 size but the other parts can vary in size (Hermansson, 2006). For the different components of the subassemblies of toner cartridge model CF280X, see Figure 3. This can be found in a larger scale in Appendix 2 – Technical drawings.

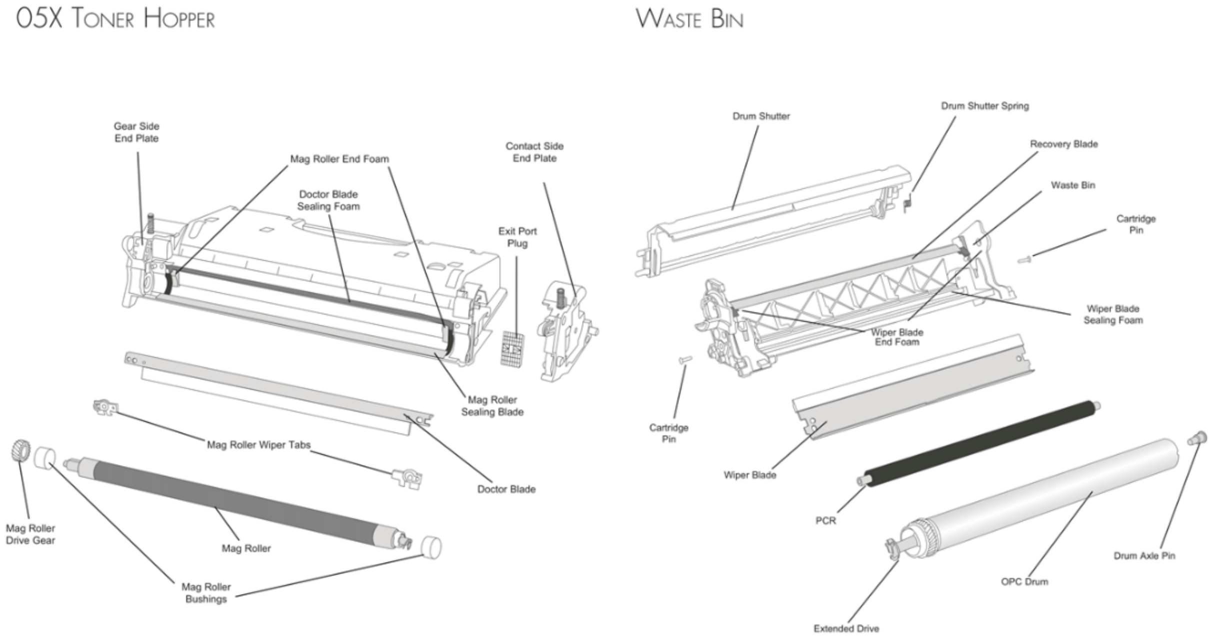

Figure 3. Toner Hopper components and waste bin components of HP CE505X (same as CF280X), taken from Static Control Components technical documentation (SCC, n.d).

4.2.2 The printer toner market

The market for printer toner is estimated to grow from USD 3.9 billion 2018 to USD 7.35 billion in 2028 (Fiormarkets, 2020). This increase is caused partially by the shift from ink-preference to toner-preference, cost effectiveness and reduction of waste. Fiormarkets (2020) states that the main obstacle for even faster growth of the toner market is the environmental impact of ink cartridges.

When purchasing a toner cartridge there are mainly two options, buy from an Original Equipment Manufacturer (OEM) or buy a remanufactured one (Chung et al., 2013). An example of a purchase from OEM is if a company's printer is from HP, the cartridges are also purchased from HP. Chung et al. (2013) continues by stating that remanufactured cartridges are often cheaper than OEM ones.

In general, a toner cartridge can be remanufactured up to four times and they are usually about 97% recyclable (Chung et al., 2013). This indicated that less virgin material must be used in manufacturing. Because of this, a remanufactured cartridge uses about 70% less material resources compared to the OEM ones over the course of their life cycle (Chung et al., 2013).

4.3 Products at Scandi-Toner

In the same pace as new toner cartridges arrives on the market, Scandi-Toner must adapt and find new ways of remanufacturing that specific model.

Which type of toner cartridge it is makes a large difference in how easy the cartridge is to remanufacture. Some models have visible and easily accessible sprints and screws, other have hidden ones (Hermansson, 2006). Sometimes other parts must be damaged to be able to reach the sprints. The part that is always replaced, with no regards to model or condition, is the OPC drum (Hermansson, 2006).

One commonly remanufactured toner cartridge is the model HP CF280X which is the one examined in this report and seen in Figure 4 .

Figure 4.Toner cartridge model HP CF280X (Bläckfisken, 2019)

4.4 Difficulties with remanufacturing toner cartridges

A study performed by Williams & Shu (2000) investigated the reasons to why some parts are discarded and not reused in the remanufacturing process of toner cartridges. The study was conducted with the purpose of identifying problematic areas in the toner cartridges design in relation to remanufacturing and aimed to help formulate design strategies to improve the remanufacturing (Williams and Shu, 2000).

Williams and Shu (2000) identified the 13 reasons for the discard as the following:

- ***Broken protrusion*** – Various structural protrusions, such as connecting arms or guide fins, were easily damaged and broken.
- ***Coating damage*** – Especially the magnetic roller's coating was susceptible to scratches, and some could not be repaired.
- ***Contamination*** – To work properly, some parts must be free of dirt and grease. Disposal of parts was caused by toner dust interfering seals and the difficulty to remove grease from plastic surfaces.
- ***Core quality*** – Smaller companies could not always regulate the core supply and cores that were suspected to be inadequately remanufactured earlier may result in a discarded cartridge rather than allowing the possibility of concealed damage.
- ***Cosmetic*** – Visual defects such as scratches and stickers are not allowed since the remanufactured toner cartridge should look as new or better.
- ***Deformation*** – If the core had been deformed in some way in forms such as breakage, distortions, or bends, and could not be repaired - it got discarded. This does not, however, include protrusions.
- ***Glue*** (degradation of) – The degradation of glue commonly caused a loose or missing seal which resulted in discard of the part.

- ***Joint damage –*** When damage was identified at the meeting point between two parts it was called joint damage.
- ***Missing part –*** If no damage, except the missing part, could be identified and no spare parts were available, the core could be discarded – if not stripped of its functional parts, depending on the needs of the production.
- ***Overstock –*** Lack of space for inventory entailed disposal of usable parts due to overflow.
- ***Sacrificial –*** Some parts had to be damaged to access other inner parts of the toner cartridges. These parts were classified as sacrificial parts.
- ***Technology change –*** When a modification was made in a specific part it entailed a change in the remanufacturing process – adapted to the newer model. This resulted in disposal of some older parts.
- ***Wear –*** Various parts with coating got worn and consumed from expected use.

The explanations for the discard of parts differed due to the size of the remanufacturing company. The most common discard reasons for larger companies were glue, coating damage and broken protrusion, while wear, core quality and deformation were the most common for smaller companies. However, broken protrusion and glue were common in both big and small companies. Therefore, strategies to improve the design for remanufacturing considering these two problems were developed. (Williams and Shu, 2000)

Regarding "*broken protrusions*", guidelines were formed to reduce the number of discarded toner cartridges due to this reason according to Williams and Shu (2000):

- If possible – avoid protrusions in the design
- Use stronger protrusions
- Create/Use modular designs

The problem regarding the *degradation* or *contamination of glue*, leading to leaks in the toner cartridge, could be evaded by the following:

- Better joining process
- Investigate the possibility of a better design to contain toner

Otherwise, designing with disassembly in mind contributes to more efficient remanufacturing of the toner cartridges and should be considered during the design process (Williams and Shu, 2000).

In earlier designs, toner cartridge manufacturers used clips to attach parts and components together. However, in the current designs the OEMs try to use molding and/or melting with the aim to counteract disassembly. In return, Scandi-Toner and other remanufacturing companies develop methods and tools to cope with the attempts to make remanufacturing more difficult through design changes. For example, Scandi-Toner developed a method for opening the toner cartridge to refill toner, using a saw, as well as a clamp that could reseal the toner cartridge after the refill. Furthermore, they created certain fixtures for specific steps within the remanufacturing process. (E Sundin and Östlin, 2005)

In addition to the difficulties identified by Williams and Shu (2000), further areas where improvement was needed regarding remanufacturing toner cartridges were recognized by Erik Sundin et al. (2012), regarding toner characteristics. The retrieved cores contain residues of toner inside the toner cartridges making the cleaning process challengeable. Toner is hard to isolate due to its characteristics being very light, easily attaches to most surfaces and penetrating unreachable areas. Furthermore, the employees working in production are negatively affected by toner by getting irritated eyes and throats. Additionally, the operated cleaning method using highly compressed air to remove residual toner causes loud noise disturbing the workers.

Furthermore, Erik Sundin et al. (2012) identifies difficulties regarding OEMs vs. independent remanufacturers. The present designs for toner cartridges are more difficult to remanufacture than the design used in the 1980´s. Instead of using clips to hold the parts and components together as earlier, the new design includes molding parts together and making disassembly harder. The reason for the change in design is the competition for the market between the OEM and the independent remanufacturers – whereas the OEM strives to sell new products while remanufacturers restore the used toner cartridges. Therefore, the OEM changes their designs with the aim to counteract remanufacturing resulting in that the remanufacturers must damage the toner cartridge to be able to refill the toner. Moreover, it results in the need of special tools to disassembly the toner cartridge and remanufacture. (Erik Sundin et al., 2012; Williams and Shu, 2000).

Further, alongside the identified difficulties with remanufacturing toner cartridges, Ijomah et al. (2007) identified barriers for remanufacturing in general by using case studies. Both technical and non-technical barriers affecting products that are or are meant to be remanufactured were identified (Ijomah et al., 2007).

The technical barriers are according to the outcome of the characteristics regarding the design and manufacture, which includes poor disassembly and usage of materials with less durability. Disassembly is an essential activity in the remanufacturing process and if a product is not capable of disassembly it is probably not remanufacturable since the internal parts are non-accessible for cleaning, restoration, and upgrade. (Ijomah et al., 2007)

The non-technical barriers, such as costs and customer satisfaction, are also affecting the remanufacturability but are not considered in this project.

5 Case study

The case study consists of an analysis and assessment of one specific toner cartridge model's remanufacturability with the implementation of steps originating from EN45553:2020. The aim of this case study was to calculate the remanufacturability of a toner cartridge model, which should be presented in a numeral score.

In line with EN45553:2020, the initial step in the case study was to chart the remanufacturing process for the chosen product, in this case the toner cartridge CF280X. The mapping of the remanufacturing process was conducted through data collection, which was implemented with the aid of interviews and observations. How the data collection was implemented is described in subchapter 5.1. Each process step identified at Scandi-Toner was observed and described together with complementary information from the data collection, presented as data collection results in 5.2, before they were compared to the general process steps and product attributes in the RemPro matrix, seen in chapter 5.3. Further, this analysis was then translated into TC criteria (*toner cartridge criteria)* which the toner cartridge was set to meet to assess its remanufacturability. The revised RemPro Matrix, seen in Table 7, was verified with the final analysis of the TC criteria. Lastly, the remanufacturability of the toner cartridge was calculated. Figure 5 illustrates the structure of the case study.

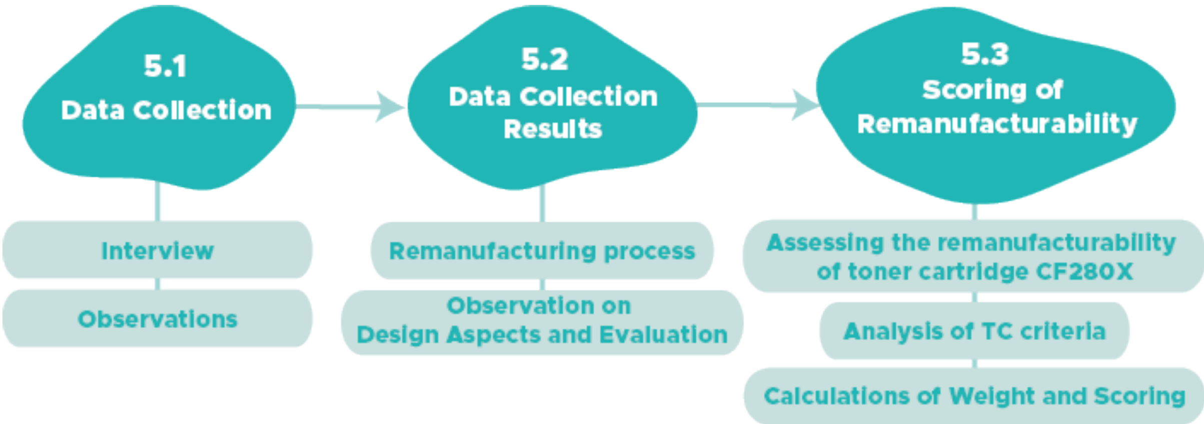

Figure 5. Overview of the Case study methodology

5.1 Data Collection

Prior to the interview with Scandi-Toner, questions were prepared, which is described in subchapter 5.1.1. Interview Questions. These were formulated with the aim to contribute to information answering the research questions. However, they were created from the information gathered in the literature study regarding how to successfully conduct an interview and with the knowledge gained about the company. In addition to the interviews, data was collected from the video material send by Scandi-Toner, previously performed studies about Scandi-Toner's process and technical specifications of toner cartridges in general.

The interview was performed with Magnus Gustavsson, responsible for production and storage at Scandi-Toner. The result of the interview and the observations is described in subchapter 5.2. *Data collection results*.

5.1.1 Interview Questions

The interview was divided into three separate parts where the first part included question about the employee and their role at Scandi-Toner. Part two included questions about the production as well as the product and part three included questions correlating to the research questions. All interview questions can be read in Appendix 3 – Interview questions.

The first part of the interview included questions about the employee, such as "*What is your role at Scandi-Toner?*" and "*What are your task assignments*". These questions contributed to a better understanding of the company, the production, and the employee. This aided with the understanding and interpretation of the interviewee's answers in the rest of the interview.

The second part of the interview, containing questions about the production, toner cartridges and their functionality as well as the remanufacturing at Scandi-Toner included questions such as *"What are the different steps when remanufacturing a toner cartridge?", "Describe a remanufacturing process from incoming cores to delivery of the remanufactured toner cartridge.",* and *"Within each step, are there any difficulties?".* These questions contributed to a clear understanding of the remanufacturing process at Scandi-Toner, how it was done and what the challenges were. Furthermore, the answers could compile information about parts and features that complicate or aggravate the remanufacturing of toner cartridges.

The third and final part of the interview included questions correlating to the research questions that were not answered in the previous parts of the interview which gave the possibility to ask follow-up questions and clarify ambiguities.

5.2 Data collection results

The results from the data collection within the case study is summarized below. Subchapter 5.2.1 describes the identified remanufacturing process at Scandi-Toner together with a description of the process. In subchapters 5.2.2 *Observations on Design Aspects and Evaluation,* other relevant information was gathered regarding e.g., design aspects and evaluation of remanufacturability.

5.2.1 The Remanufacturing process at Scandi-Toner

The interview together with the observing videos from Scandi-Toner resulted in a mapping of the remanufacturing steps, which conveys the order of each step and how they were conducted. Information was given of difficulties within each step and design features that counteract the remanufacturing. A cartridge model suited for remanufacturing and common within the production at Scandi-Toner was identified as CF280X. Moreover, this data was later confirmed by previous studies (Hermansson, 2006) and the technical specification on cartridge model CF280X (SCC, n.d).

The remanufacturing process at Scandi-Toner begins with these four steps: *cleaning*, *inspection*, *storage*, and *disassembly*. These initial steps are conducted consecutively, except for the fact that toner cartridges and parts possibly being stored for years before the rest of the remanufacturing process is completed – initiated by an incoming order. In the fourth step, the core is disassembled into two subassemblies, leading to the second phase of remanufacturing.

The two subassemblies are called *the Hopper* and *the Waste bin* and can be seen in Figure 3. These two subassemblies are disassembled further, inspected, cleaned, and reprocessed before being assembled. Within the *Hopper* and the *Waste bin,* the process steps following the disassembly are conducted separately on each subassembly as well as some specific parts – unrelated to each other. For example, one part of the *Hopper* is reprocessed at the same time as another part is cleaned. When disassembling, the separated parts is stored in different labeled containers together with similar parts waiting to be inspected, cleaned, and reprocessed. Hence the exact same parts do not have to be used for the same toner cartridge when assembling the *Hopper* and *Waste* bin.

The final phase of the remanufacturing process of CF280X at Scandi-Toner are the steps *reassembly, testing* and *storage*. In the reassembly step, the product is assembled into one complete unit and thus categorized as one step.

The identified remanufacturing process at Scandi-Toner can be seen in Table *6*, together with a brief explanation of the process steps. This is the remanufacturing process as described by Gustavsson (2020) and summarized and interpreted by the researchers. Further observations and important data collected from the interviews are described in subchapter 5.2.2.

Table 6. Remanufacturing process at Scandi Toner as described by Gustavsson (2020) and interpreted by the researchers. The studies toner model is CF280X

#	**CF280X Remanufacturing process at Scandi Toner**	**Description**
1	Cleaning	Basic initial cleaning of excess toner after cores arrives at factory
2	Inspection	Visual inspection and sorting before storage
3	Storage	Stored until ordered
4	Disassembly	Separation of the two subassemblies (hopper and waste bin)
5	Disassembly	Disassembly of the parts of the two subassemblies
6	Inspection	Visual inspection of parts
7	Cleaning	Cleaning is completed in steps • Cleaning with compressed air, performed after step 5 (to hopper and waste bin) • Cleaning with isopropyl alcohol, performed for applicable components during reprocessing or assembly
8	Reprocessing	Reprocessing of the parts of the two subassemblies
9	Assembly	• Reassembly of the parts of the two subassemblies: • Reassembly of the subassemblies
10	Testing	Final test of the remanufactured toner. Possible iteration of step 4-8 if test not passed
11	Storage	Stored until sent to customer

5.2.2 Observations on Design Aspects and Evaluation

Apart from the description of the remanufacturing process steps, the interview and the video observations describe improvement areas and other relevant information about toner cartridges. Design aspects that affected the remanufacturing of the toner cartridge was also identified, evaluated, and used as the basis for the *TC criteria* described in chapter 5.3.

Other aspects not necessarily connected to a specific step in the remanufacturing process that also affects Scandi-Toner's work are:

- Scandi-Toner used about one third of the cartridges that entered the production, either for complete remanufacturing or to be used as spare parts. The other cartridges were discarded for reasons like being a cheap copy of an OEM product. These copies cannot be remanufactured as they are of much lower quality than OEM products. Another reason for discarding a cartridge was if it had been remanufactured several times prior.
- Scandi-Toner manufactured mostly toner cartridges from the brands HP and Canon since these had the highest demand on the market.
- When evaluating if the incoming toner cartridge model was remanufacturable enough, apart from technical criteria, other factors like economy plays an important part as well. In this case the CEO of Scandi-Toner had to be involved to decide based on technical factors, economy, and profit for the company. When asked what a method of remanufacturability should consist of, Gustavsson also mentioned production cost and production lead time.

Identified design features complicating the remanufacturing process at Scandi-Toner:

- If the body of the cartridge is narrow and deep it is harder to clean and reach access points and fasteners.
- Small parts like gears, pins and screws can be difficult to reach, handle and reassemble. Especially since they must be assembled at the exact same place. Sometimes the gears have a coating of fat which complicates the handling and can leave grease stains on other parts.
- OEMs deliberately try to complicate the remanufacturing for other companies by, for example, making cartridges narrow and thus difficult to reach into. Or by making it impossible to refill a cartridge without permanently damaging the construction.
- The dream scenario when remanufacturing a toner cartridge is a core with few fasteners (for example one pin and two screws) and that no permanent damage (like drilling holes) must be made to the product. Also, fewer parts are beneficial since this reduces the risk of something going wrong in disassembling and assembling parts.

  Products today tend to get more complicated by introducing more digital content and smaller parts. There are some products designed decades ago that are easy to remanufacture because of easy access and contains of a few large parts.

- The removal of fasteners is the most time-consuming step, particularly regarding the disassembly. The cartridges are designed so that these are often difficult to access and remove. Destructive disassembly is often required.
- Some cartridge models are more sensitive, particularly to testing. Factors such as advanced electronics (in both toner and printer), printers' sensitivity to tolerances, worn parts and contacts play key parts. These factors are therefore important, particularly regarding the testing phase.
- Indication tabs is a feature that distinguish different toner cartridge models. These actuate switches inside the printer so that it can detect whether the cartridge is installed or not. Locating these and determining that they are in working condition is key in successfully remanufacturing the toner cartridge.
- The toner powder is volatile and difficult to isolate. It is irritating to the respiratory tract as well as it penetrates hard-to-reach spaces. This could sometime contribute to a hazardous working condition for the workers.
- The general method for cleaning used at Scandi Toner is compressed air and is conducted 100% by hand. It is an effective way of cleaning both large and small parts, however it can sometimes be damaging to sensitive parts. It is therefore key to identify sensitive parts and remove them for separate cleaning. This is also one of the reasons step 5-9 is adjusted to better suit the remanufacturing of the toner-components.
- Sometimes special machines are used to separate hopper and waste bin (all other work is manual).
- Bins/racks with a capacity of about 40 units are used for logistics and storage. Storage is not a key step in the remanufacturing of toner cartridges in general.
- The work process is based on reusing as many parts as possible. Only the OPC drum is replaced each time. Other parts are reused if they are intact and not defective. It is key to access the parts of the core to do this, particularly the inspection but also for the remanufacturing process in general.

5.3 Scoring of remanufacturability

To assess the remanufacturability of a toner cartridge two ways of grading the product were created. The first being an assessment on whether the product is at all remanufacturable, using *must* criteria, and the other one analyzing how well suited the product is for remanufacturing (*should* and *might* criteria), evaluated from a total score of all the three types of criteria.

The method for assessing the remanufacturability is described in subchapter 5.3.1. where the analysis of the data collection results was conducted together with identification of TC criteria. The criteria were then analyzed, described in subchapter 5.3.2, and a score was calculated as described in subchapter 5.3.3. Lastly, the assessment of the toner cartridges, was verified with the final analysis of the TC criteria. The result and score can be found in subchapter 5.3.4. Figure 6 illustrates the structure of the case study.

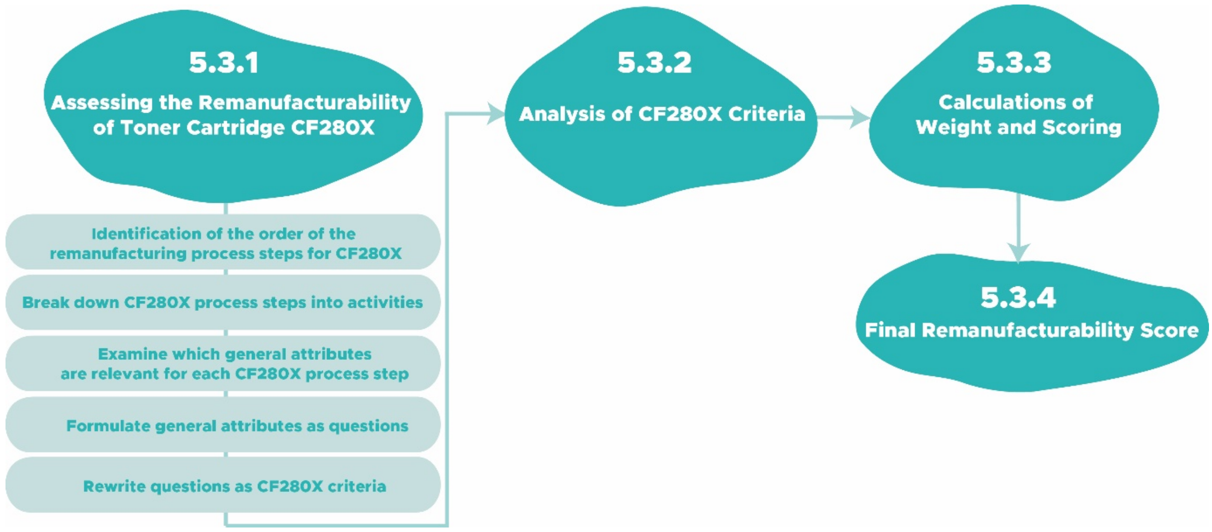

Figure 6. Overview of subchapter 5.3. Scoring of Remanufacturability

5.3.1 Assessing the Remanufacturability of toner cartridge CF280X

When the CF280X remanufacturing process steps had been established, the target group for the developed method was chosen. In this case study the target group were chosen to be companies and manufacturers that need a method to evaluate the remanufacturability of a certain toner cartridge model. Initially, the identified process steps described in subsection 5.2.1 were compared to the attributes A1-A5. This was conducted to identify correlations between the applicable general criteria within each product attribute and the process steps for the toner cartridge CF280X using the RemPro Matrix show in Table 5.The adapted matrix is shown in Table 7.

*Table 7 RemPro-matrix for the Scandi-Toner case. Changes compared to Table 5 are marked with * and is the result of analysis of the TC criteria.*

Product Attribute		Remanufacturing Process Steps						
		Inspection	**Disassembly**	**Cleaning**	**Reprocessing**	**Assembly**	**Testing**	**Storage**
A1	Ability to be identified	X	X*	X*	X*		X	*
A2	Ability to locate access points and fasteners		X			X		
A3	Accessibility of parts	X*	X	X	X	X	X	*
A4	Ability to be disassembled/assembled		X			X		
A5	Wear and damage resistance	X	X	X	X	X	X	X

The adapted Rem-pro matrix (Table 7) contains:

- **X** where fulfilled general connections **not changed** from the original
- **X*** where connections **added** in the case study
- ***** where general connections were placed, but **removed** in the case study

The crosses in the storage categories were removed because of the lack of impact storage has on the remanufacturability of toner cartridges. Toner cartridges are, in comparison with other remanufacturable products, small and durable with no parts that are damaged during storage. The OPC drum is sensitive but if handled with care, the way they are stored will not affect the remanufacturability of the model.

Criteria which need to be met by the product for the product attributes to be fulfilled were then formulated for each step of the process. For example, the product attribute *ability to locate access points and fasteners* used in EN45553:2020 could be connected to certain problems of locating fasteners found in the process at Scandi-Toner. These connections were then analyzed to find either improvement areas or parts of the EU remanufacturing standard that is not necessary for technical aspects of remanufacturing of toner cartridges.

Identification of TC criteria

Identification of criteria was conducted for each of the remanufacturing process steps for CF280X at Scandi-Toner, described in Table *6* above. The full and final list of criteria can be found in Appendix 4 – TC criteria. An example of how the analysis was conducted for one of the process steps, the disassembly of a core, is described below.

Initially, when the process step disassembly of a core was described, the key activities for disassembly was found. The disassembly was compiled by the following activities:

- Identifying fasteners and joints
- Separate drum shutter, e.g., with flat screwdriver
- Drill to push pins out, separate pins with pliers
- Put drum shutter back on waste bin and set aside
- Placing disassembled parts in different separate containers

The activities were then compared with the general criteria connected to the product attributes (A1-A5) in the EN45553:2020 to identify which general criteria that was relevant for disassembly. This was conducted by reformulating the general criteria in EN45553:2020 as representative questions, asking whether it was relevant for the analysed process step. The question was then answered using the activities identified in the prior step of the analysis. An example of the general criteria for the attribute A3 *Accessibility of parts* correlating with disassembly of core, could be seen in Table 8.

Table 8. Example of a table mapping the relevance of the typical criteria from EN45553:2020 and the activities within process step 4 – disassembly of core

General criteria from EN45553:2020	Representative question	Relevance for step 4	Answer
Access to parts during disassembly	Is it important to access parts during disassembly?	Yes	Parts within the toner cartridge must be disassembled to remanufacture hence parts must be accessible during disassembly.
Modularity of the parts of the ERP	Are there modular parts? If yes – are they accessible during disassembly?	No	Toner cartridges are not modular – access to modules is irrelevant.
Access to fasteners, e.g., joints, gripping points and breaking points.	Is access to fasteners needed during disassembly?	Yes	Access to fasteners is needed during disassembly.

Each of the relevant attributes in EN45553:2020 were compared to each of the remanufacturing steps, creating several tables as the one seen in Table 8. The relevant general criteria identified was then rewritten into new *representative questions* for all the CF280X process steps, and these represented the applicable TC criteria connected to the remanufacturability. An example can be seen in Table 9 below.

Table 9. Example of questions asked in each process step.

Process step	Representative question	Answer	Product Attribute
1. Initial cleaning	Can the outside of the toner cartridge be cleaned without damaging any parts?	Yes/No	A5 – Wear and damage resistance during the remanufacturing process steps.

Efforts were made to formulate the questions in a language that could be easily understood by anyone working with the product, in comparison to the EU standard, which is written in a technical, formal manner. These representative questions were then analyzed and rewritten as case specific *TC criteria.* Each criterion connects to a CF280X process step and corresponds to a product attribute, see Table 10. The TC criteria were then categorized, by factors the product *must, should* or *might* fulfill, depending on their relevancy for remanufacturability. For example, it was found that during assembly it *must* be possible to assemble all parts of the product regardless of handling in previous steps, but the parts of the product *should* be possible to handle without difficulty because of their size, shape, weight, or other factors. Further, it was found that there *might* be standardized types of fasteners used in the construction, easing the manufacturing. This distinction between different kind of criteria were found to be critical for the assessment and evaluation of remanufacturability, described in section 5.3.2. An example of the new TC criteria could be seen in Table 10, together with the evaluation if the core meets the criteria.

Table 10. List of TC criteria. Table shows step 4: disassembly of parts. For complete list of TC criteria see Appendix 4 – TC criteria

#	CF280X Process step	TC criteria	Attribute	Core fulfillment of criteria
4	**Disassembly of core**	The unit *must* be able to be disassembled using available methods	A4	Yes
		The unit *must* be able to be accessed using available methods	A3	Yes
		A single operator *should* be able to disassemble the unit without assistance	A4	Yes
		The disassembly of the product *should* need an appropriate number of tools	A4	Yes
		The disassembly of the product *should* require a low number of fasteners to be loosened	A4	Yes
		The product *should* use as few different kinds of fasteners as possible	A4	No
		There *should* be indications on where and how to disassemble the product	A2	No
		There *should* be standardized types of fasteners used in the construction	A4	No
		Sensitive parts of the construction *might* be clearly indicated or noticeable	A5	Yes
		There *might* be jigs available which can be used during disassembly	A4	Yes
		There *might* be diagrams and/or manuals describing how to disassemble the product	A2	Yes

This was completed for all the CF280X process steps, before conducting the calculations of the total score.

5.3.2 Analysis of TC Criteria

The first analysis considers the *must* criteria which were set for the CF280X toner cartridge model. Using an excel sheet, the practitioner fills in whether the product meets each criterion for all the process steps. The answers are then summed up and the product receives a binary score. In this first analysis, the product can either be deemed as suitable for remanufacturing, or not suitable for remanufacturing. If the toner cartridge fails to fulfill any of the criterion which has been set as a must-fulfill, it is deemed as not suitable for remanufacturing.

When the product has been approved as remanufacturable from the initial analysis using the must criteria, it is analyzed using the *should* and *might* criteria. The *should* criteria are the ones that will have a significant role for the remanufacturability of a product but will not be crucial for it. For example, it will be beneficial for the remanufacturability of a product if it uses few different types of fasteners, but it will still be remanufacturable if it does not.

Likewise, the *might* criteria are even less significant for the remanufacturability of a product but might have an impact when all other criteria have been fulfilled.

5.3.3 Calculations of Weight and Scoring

From the formulated *must, should* and *might* criteria, a score needed to be calculated. The difference in importance of the criteria were given a certain weight. The total score of criteria, R, were formulated as equation (1):

$$R = (\beta_x R_x + \beta_y R_y + \beta_z R_z)/3 \tag{1}$$

$$\boldsymbol{X} = must\ criteria$$

$$\boldsymbol{Y} = should\ criteria$$

$$\boldsymbol{Z} = might\ criteria$$

$$\beta - weight\ coefficient\ for\ criteria\ type, \qquad \beta > 0, \sum \beta = 1$$

The scoring was formulated as a binary clause (2) with the two positions:

$$x_{i,p}, y_{i,p}, z_{i,p} = \begin{cases} 1\ if\ criteria\ is\ met\ (yes) \\ 0\ if\ criteria\ is\ not\ met\ \ (no) \end{cases} \tag{2}$$

The different *must*, *should* and *might* criteria were separately calculated in each process step and then summarized to form a summation of each criteria for the product (3), (4) and (5). The equations for summation was as follows:

Must criteria:

$$R(\boldsymbol{X}) = \sum_i \sum_p \frac{\alpha_p}{l}\ \boldsymbol{x_{i,p}} \tag{3}$$

$$\boldsymbol{X} = [x_{i,p}], \qquad i = 1 \dots l, \qquad p = 1 \dots s,$$

$$l = number\ of\ must\ criteria$$

Should criteria:

$$R(\boldsymbol{Y}) = \sum_j \sum_p \frac{\alpha_p}{m}\ \boldsymbol{y_{i,p}} \tag{4}$$

$$\boldsymbol{Y} = [y_{j,p}], \qquad j = 1 \dots m, \qquad p = 1 \dots s$$

$$m = number\ of\ should\ criteria$$

Might criteria:

$$R(\boldsymbol{Z}) = \sum_k \sum_p \frac{\alpha_p}{n}\ \boldsymbol{z_{i,p}} \tag{5}$$

$$\boldsymbol{Z} = [y_{k,p}], \qquad k = 1 \dots n, \qquad p = 1 \dots s$$

$$n = number\ of\ might\ criteria$$

In equation (3) - (5) above, a weight coefficient α was added to enable the adjustment of the relative importance of the different CF280X process steps. However, determining this was not considered in this case ($\alpha = 1$).

$\alpha_p - weight\ coefficient\ for\ CF280X\ process\ step\ p,\ \alpha_p > 0, \sum \alpha = s,$

$s = number\ of\ CF280X\ process\ steps\ (total\ 11)$

Weight coefficient type β was added to adjust the relative weight of the different criteria types in the total remanufacturability score calculated in equation (1). In this case, all *must*, *should* and *might* criteria were set of equal importance, and therefore calculated according to equation (6), (7) and (8).

$$\beta_x = \frac{l}{l+m+n} \quad (6) \qquad \beta_y = \frac{m}{l+m+n} \quad (7) \qquad \beta_z = \frac{n}{l+m+n} \quad (8)$$

How the summation of scoring from each process step would look if all 58 TC criteria were fulfilled is described in Table 11. The criteria are categorized by general process step and applicable attribute. Note that this table show the results of the criteria's score, and not the result of the case study. In this case, this simply means that the table show *the number of total criteria* for each step (because all criteria in this case are of equal weight, as shown by equations (6)-(8)).

Table 11. Results of maximum remanufacturability score sorted by RemPro-matrix in Table 7 In other words, this shows the number of criteria attributed to each remanufacturing process step and attribute. The table also shows the sum for each respective step and attribute

Product Attribute		Remanufacturing Process Steps							∑Attributes
		Inspection	Disassembly	Cleaning	Reprocessing	Assembly	Testing	Storage	
A1	Ability to be identified	5%		3%	3%		5%		17%
A2	Ability to locate access points and fasteners		5%			3%			9%
A3	Accessibility of parts	3%	5%	2%	2%	2%	3%		17%
A4	Ability to be disassembled/assembled		19%			9%			28%
A5	Wear and damage resistance	5%	7%	2%	2%	5%	2%	3%	29%
	∑Steps	14%	36%	10%	7%	19%	10%	3%	100%

All of the above calculations of weight and scoring were performed in the case study and the final result is presented below in subchapter 5.3.4.

5.3.4 Final Remanufacturability Score – Case Study

Table 12 presents the final scoring of remanufacturability of the toner cartridge model CF280X. The *must* score determines whether the product is remanufacturable at all, whereas the score **100 %** represent the answer yes for CF280X. The *must, should* and *might* scores are summed up – resulting in the total remanufacturability score of **90%**. See Appendix 4 – TC criteria for full scoring of criteria.

Table 12. Scoring results from CF280X - case

	Rx (must score) [%]	**Ry (should score) [%]**	**Rz (might score) [%]**	**R (total score) [%]**
CF280x at ST (case)	100	73	100,0	**90**

To see how the scoring is divided between different process steps, see Table 13. For the case of *disassembly of core* as described in section 5.3.1 the TC criteria score was combined with those of *disassembly of parts* and sorted by attribute.

Table 13. Case results as proportional fulfillment of criteria sorted in RemPro-matrix

Product Attribute		**Remanufacturing Process Steps**						
		Inspection	**Disassembly**	**Cleaning**	**Reprocessing**	**Assembly**	**Testing**	**Storage**
A1	Ability to be identified	100%		100%	100%		100%	
A2	Ability to locate access points and fasteners		67%			50%		
A3	Accessibility of parts	100%	100%	100%	100%	100%	100%	
A4	Ability to be disassembled/assembled		82%			100%		
A5	Wear and damage resistance	100%	75%	100%	0%	100%	100%	100%

From this table one could see which process steps are in most need for improvement to increase the remanufacturability of the CF280X model. Note that Table 13 show how many of each TC criterion is fulfilled for each cell in the table, not in relation to each other. In Table 11 one can see that 19% of the total criteria score is attributed to disassembly of attribute A4, and in Table 13 82% of these are fulfilled, meaning 9 of the 11 criteria for this category was met. Another example is the reprocessing of attribute A5, showing 0% fulfillment in Table 13. However, Table 11 shows that only 2% (1 criteria) correspond to this category.

6 Method for remanufacturability assessment

Using the results from the case study together with the literature study – a method to measure the remanufacturability for different toner cartridges was developed.

6.1 Development of MAR

The first step of developing the *Methodology for Assessment of Remanufacturability*, MAR, was to establish the target group and the aim of the methodology. This was accomplished by discussing the various potential target groups and what results the researchers were aiming for. The target group was selected from where the most impact could be accomplished within the scope of the project, together with what could be achieved with the assets provided. Clarifying the target group as well as the aim of the methodology facilitated the development of MAR and contributed with a common goal for the authors of this report.

After establishing the aim of the development of MAR, the target group was specified further. The aim for MAR was "*creating a method for establishing/producing a model for assessment of remanufacturability that could be performed by any company, making it possible to create a model for assessing the remanufacturability of any energy-related product*". This could be a company remanufacturing either toner cartridges or other energy-related products.

This meant that the researchers chose to expand the target group when developing MAR. From solely remanufacture companies that assess the remanufacturability of new models of toner cartridges, the target group was also expanded to include designers aiming to assess the remanufacturability of the products that they are developing. This was conducted with the aim to make the developed methodology more useful for a broader target group through making the methodology adaptable to the user of MAR.

However, lessons learned from the case study was the foundation for the development of this methodology. Efforts were being made in making the results from case study more generally applicable on other toner cartridge models.

To make sure the methodology could be understood by anyone not knowledgeable about remanufacturing, the language of the steps and attributes were modified. Also, steps that had taken a long time to finish in the research and case study were presented and simplified in the methodology to enable a faster process for the user.

6.2 MAR

When introduced to the MAR document the user is first presented with an introduction. The introduction contains a description of who MAR's intended users are, expected results from the method and a brief introduction to remanufacturing. The EU standard, from which MAR is developed, is described both in remanufacturing steps and product attributes. The aim of this introduction is to increase the user's understanding of the method and eliminate mistakes in the following steps. Figure 7 illustrates the general steps for conducting the MAR assessment.

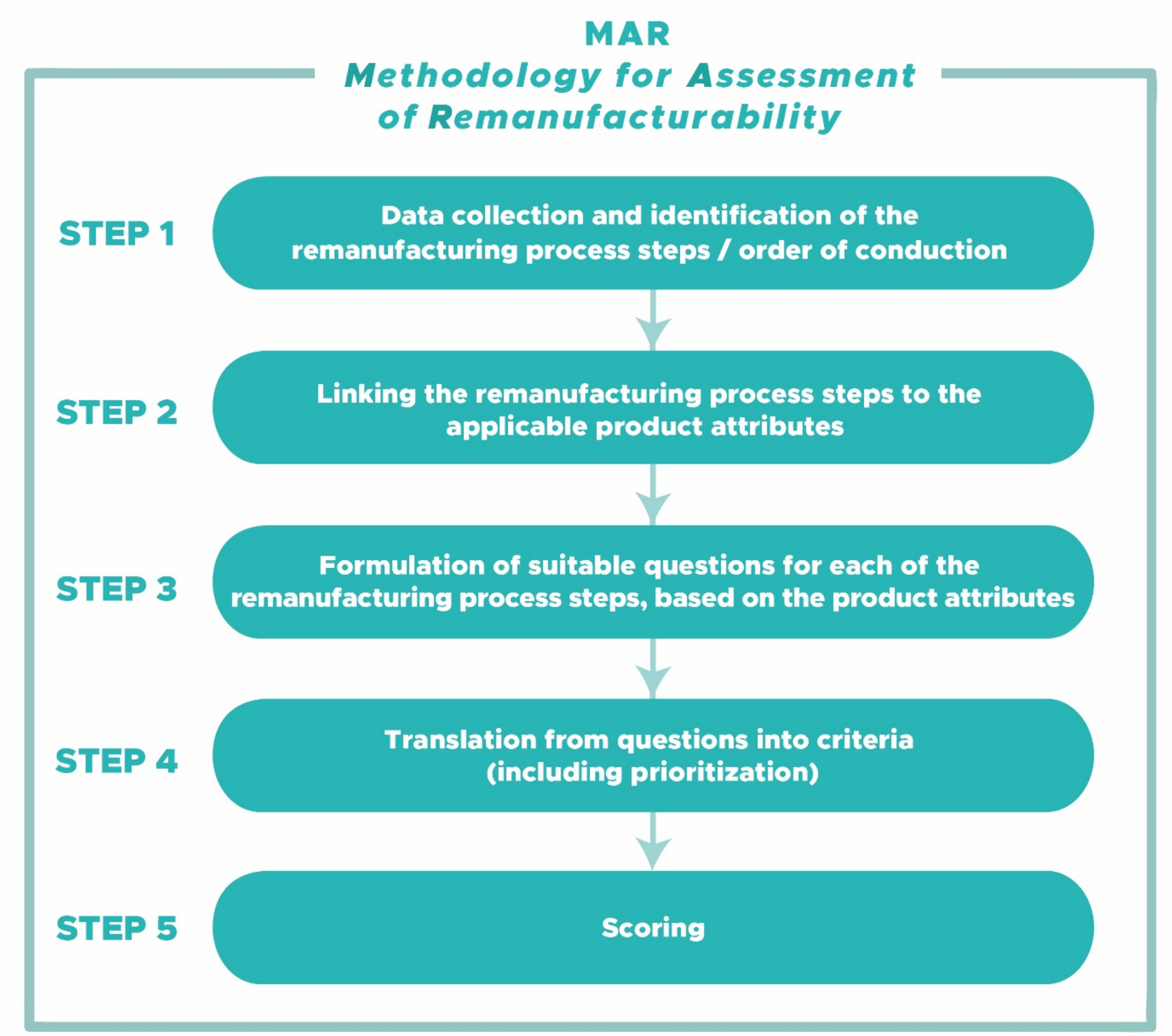

Figure 7. Overview of the procedures for conducting MAR.

The following instructions describe the steps that are recommended for the user to follow when conducting an assessment of remanufacturability of one specific toner cartridge model:

Step 1: Data collection and identification of the remanufacturing process steps / order of conduction

Input data: A product for which remanufacturability is to be examined.
Useful data collection methods: Interviews and observations.
Output data: A step by step process list with short description of each step.

Procedure:

1. Gain knowledge about the remanufacturing process by either interviewing or conducting observations at the remanufacturer. This can be done either by interviewing remanufacturing staff and/or by observing the remanufacturing process live or via recordings. If the product has no official remanufacturing process available, it could either be simulated or represented by the remanufacturing process of a similar product.

2. Make a process tree showcasing the different process steps, see example below. Make sure to include all steps, even if some are conducted simultaneously. This process tree will be the output of step 1.

Table 14. An example of a generic remanufacturing process for a fictive product. As can be seen in this example, some of the seven general process steps which are always part of a remanufacturing process are conducted multiple times.

REMANUFACTURING PROCESS OF A GENERIC TONER CARTRIDGE	
Cleaning of entire product	
Inspection of entire product	
Storage until requested by customer	
Disassembly into two components, A and B	
Hopper	**Waste bin**
Cleaning and inspection	Cleaning and inspection
Reprocessing	Reprocessing
Reassembly	Reassembly
Cleaning	Cleaning
Reassembly of part A and B	
Testing of complete remanufactured product	
Potentially improvements based on test results	
Storage until delivery	

Step 2: Linking the process steps to the applicable product attributes

Input data: Output from Step 1 + descriptions of the product attributes (A1-A5) + Empty linking table (both found in Appendix 5 - Methodology for Assessment of Remanufacturability (MAR))
Output data: An overview of the link between the product attributes and process steps for the specific product.

Procedure:

1. Use the table in Appendix 5 - Methodology for Assessment of Remanufacturability (MAR) and fill in the *process steps* found in step 1.
2. Assess the relevancy for each *product attribute* on every *process step*, based on knowledge on the remanufacturing process and mark that link in the table.

Step 3: Formulation of suitable questions for each process step, based on the product attributes
Input data: Output from Step 2
Output data: A list of questions based on the product attributes, which need to be met by the product

Procedure:
Working with each process step separately, formulate questions which aim to collect data connected to the product attributes which were considered relevant for the current process step. Use the table which was filled in during Step 2 as well as the example assessment attached in Appendix 5 - Methodology for Assessment of Remanufacturability (MAR) for reference.

Note:

- Think of the questions as check lists that should be able to be used to make sure all the data, which is needed in order to assess the remanufacturability, has been collected.
- Make sure to note what product attribute each question aims to provide information on.
- The same question can be asked multiple times in different process steps, if the information could have been changed during the previous steps.

Step 4: Translation from questions into criteria (including prioritization)
Input data: Output from Step 3
Output data: A list of criteria

Procedure:

1. Rephrase the questions formulated in Step 3, so that they are criteria which need to be met rather than questions. For example, the question "Is it possible to clean the unit using available methods?" can be rephrased as "The unit must be able to be cleaned using available methods".
2. After initial formulation, the criteria should be prioritized based on how significant they are for remanufacturability. There should be a distinction between criteria which are crucial for remanufacturability, and ones that are advantageous, but not crucial, if met. This will be important for the following steps.

Note:

- Make sure to note what product attribute each criterion aims to provide information on
- One way of differentiating the criteria is to formulate the crucial criteria as *must* criteria (for example, "the unit must be able to be cleaned using available methods") and the advantageous, not crucial, criteria as *should* or *might* criteria (for example, "the unit should be able to be cleaned using available methods" or "the unit might be able to be cleaned using available methods)

Step 5: Scoring
Input data: Output from Step 4
Useful tools for gaining input data: Some type of software that can be used for mathematical calculations and formulas, for example Microsoft Excel.
Output data: Two types of assessment of the remanufacturability of the product in question. The first one assessing whether the product is at all remanufacturable and the second one assessing how well suited the product is for remanufacturing.

Procedure:

1. Using a software, create a way to evaluate the product by the criteria by confirming or denying that it has met the criterion.
2. Sum up the results for the criteria deemed crucial for remanufacturing. If the product fails to meet even one of these criteria, it cannot be remanufactured until it has been met.
3. Sum up the results for the rest of the criteria. The number of criteria met in total will give a scoring on how well suited the product is for remanufacturing.

Note:

- Make sure to evaluate the weight coefficients and adjust them according to the analyzed. These will influence scoring, based on what is presented in section 5.3.3.

6.3 Redesign suggestions of toner cartridges

To enable manufacturers to perform a remanufacturing as easy as possible, the following design suggestions has been summarized. The suggestions are based on theory mentioned earlier in this report and the presented case study.

1. Fewer parts in the design of the cartridge are beneficial. Each part that must be separated is a risk of damaging the product or adding valuable time to the disassembly/assembly process.
2. Large parts with wide openings are easier to access and clean.
3. Avoid non-reversible fasteners like glue to minimize damage when separating parts.
4. Small details in fragile materials should be kept to a minimum, e.g., protrusions should be kept to a minimum.
5. Create a design in a durable and cleanable material to enable additional loops of remanufacturing.
6. If chips and electronics are used in the cartridge, make sure there is a way to reset these, so they do not have to be replaced with every remanufacture.
7. Parts that are often drilled into today (e.g., the toner container) could be made accessible by creating a resealable opening or a shutter to eliminate the permanent damage drilling holes creates.
8. When determining how to arrange parts in the cartridge design, prioritize placement in a way to determine the condition of the component without disassembly if possible.

7 Discussion

In this chapter the results are discussed in accordance with the theory of the report.

7.1 Theory and application

This subchapter discusses several topics regarding the presented theory and how it relates to the findings from the case study. It also touches the topic of potential future work with remanufacturing of toner cartridges.

7.1.1 Competition within the toner cartridge industry

The fact that manufacturers deliberately complicate the design of toner cartridges with the aim to counteract remanufacturing is stated in both the literature and the case study. The interview conveyed that the design today complicates accessibility to inner parts due to the size and shape, compared to the toner cartridge design "in the good old days". This is strengthened by e.g. Erik Sundin et al. (2012) who in the literature explains that the design in the 1980´s was easier to remanufacture since they used methods such as clips instead of the welding or molding that is used on a larger scale today. The reason for this is stated to be the competition between OEM and independent remanufacturers, such as Scandi-Toner. This competitiveness preventing the development of design for remanufacturing also prevents circular economy to grow.

7.1.2 The potential of working with remanufacturing of toner cartridges

There is enormous potential in the remanufacturing business in general but also in the toner cartridge business specifically. As mentioned by Fiormarkets (2020), the printer toner market is estimated to double in value the upcoming 10 years. This is huge potential for the remanufacturing of toner cartridges, both for OEMs and independent remanufacturers. One of the largest obstacles to this growth is the negative environmental impact of the toner cartridges (Fiormarkets, 2020). One could argue that one way of reducing this environmental impact is by looping the units an increased number of times, enabled by remanufacturing. This would result in less virgin material being used and the value of the cartridge will be prolonged.

7.1.3 Similarities between theory and case study

The identified process steps at Scandi-Toner discovered in the case study was corresponding well to the remanufacturing steps mentioned in the literature. Even though several steps were the same as the ones suggested in the EN45553:2020 standard, some differences were found between the case and the theory. For example, it was found that Scandi-Toner uses a different order of conduction and repeats some of the steps suggested in the standard. This was an expected finding which leads to the conclusion that all products and remanufacturing companies have their own specific process, with small changes in which process steps that are included and the order of the steps.

One thing mentioned by Scandi-Toner but not found in the literature study was how the use of electronics in toner cartridges today affects remanufacturing. Scandi-Toner mentioned how chips needs to be replaced for every remanufacturing if the ability to reset is not available. In a current digital world this is a vital step for the remanufacturing industry to keep up with. One could argue that IT is an area which needs to be updated in currently existing remanufacturing guidelines and will probably grow in importance as digitalization continues.

7.1.4 Case study discussion

To adapt the general RemPro matrix to our case study was one of the first steps in understanding the process at Scandi-Toner. The adapted RemPro (seen in Table 7) showed the differences of the remanufacturing process for different products. The RemPro matrix in the EN45553:2020 standard is filled in with the included descriptions of product attributes and process steps. These descriptions are written in a general way and leaves room for interpretation of the user. How the user is interpreting what is included in each attribute highly influence where the crosses are placed. Therefore, the matrix can be easily interpreted differently by different users and makes it more difficult to compare matrixes.

The results of the case study are based on criteria and the criteria is based on the RemPro matrix. Therefore, it can be argued that the placement of crosses in this matrix is important. As mentioned before, the descriptions of general product attributes leave some room for interpretation as the results are then not entirely objective. This matter of subjectivity in the method might affect the way the results are compared to one another but arguably not in the case of one company's ability to assess remanufacturability. Since this case study is performed to assess the remanufacturability of one toner cartridge model and find areas of improvement, this subjectivity would not matter. The results would still show areas of improvement for that specific product at one specific company. However, if one is to compare the results between two toner cartridge models it is preferably if the method is performed by the same company to avoid variation in interpretation.

To clearly state the difference of importance of the criteria in this case study, the division into *must, should* and *might* were made. The reason for this division was to create an overview of how critical the specific criteria are for remanufacturing. The categories also aim at guiding the user into knowing in which order to deal with the different areas. An unfulfilled *must* criterion should always be prioritized over a *should* or *might* criterion. One could argue that two categories would be sufficient, one for primary criteria and one for secondary. When performing MAR this is something a company can decide for themselves. However, the reason for the division into three categories was needed for identifying both critical, supporting and beneficial criteria. As mentioned earlier by Rizova et al. (2020), one of the barriers of remanufacturing and reaching maximum profitability of a product is improper product design. If *must* and *should* criteria correspond to primary and secondary criteria, the *might* criteria aims at encouraging the user to keep improving the product beyond what is required.

Weighing of the criteria was needed to reach a fair summation and a final result. The α coefficient was introduced to consider the importance of the different process steps, and the β coefficient to consider how the *must, should* and *might* criteria influence the remanufacturability scoring. In this case, the α coefficient was set so that the process steps are all equally important, due to lack of insights of which process steps are most important for the studied product and process in particular. When performing a similar study on another toner cartridge model, observations might show that some manufacturing steps has a larger impact on remanufacturability than others. In such a case, the α coefficient can be changed accordingly to make the assessment more tailored and precise. Same goes with the β coefficient - a future user of MAR might for example prefer the *must* criteria to weigh twice as much as the *should* criteria. An integration of some type of scale is also a possibility, e.g. the weights 1,3 and 9 for the *might, should* and *must* criteria. In such a case, this can easily be modified. In the case study of this report, the β coefficient is constant for all three kinds of criteria, as they have been assumed to be of equal importance. However, the fact that the criteria has been categorized based on importance prior to the scoring creates a prioritization even without the β coefficient. As stated above - a *must* criteria should always be fulfilled before a *should* criteria even if they weigh the same in further calculations. The β coefficient is therefore introduced for users who want the scoring to more clearly state which ones to prioritize.

To get a number on how remanufacturable the toner cartridge CF280X is, the criteria was summarized and added to form a result. Our result of 90% was somewhat expected. The *must* score, corresponding to if the toner cartridge is at all remanufacturable, was anticipated to be 100% (which it was) since this is a product model that have been remanufactured for several years and was recommended by Scandi-Toner to be a suitable product to investigate. However, the *should* score of 73% shows that even this product can be improved to enable better ability to be remanufactured. Since CF280X is a model Scandi-Toner likes to remanufacture, allows us to establish 90% to be a good score in the case of Scandi-Toners remanufacturing process. Whether the final score is good or bad for a company must be determined for each company individually. One company might set a limit of only remanufacturing products with a total score of 95%, another might choose a limit of 75%. Because the score already is connected to the company's manufacturing process - some general guidelines of what an acceptable score or not is, would be feasible as a future work of this project.

Shown in Table 11, 36% of the TC criteria score is related to general process step *disassembly* (19% of which is attributed to *A4 – Ability to be disassembled/assembled),* while only 3% is related to *storage.* It is reasonable to assume that while a high number, this is a reliable result, because as stated in the case study, much of the time and effort going in to remanufacturing toner cartridges goes into accessing hard-to-reach spaces and fasteners. It is also reasonable that only a small percentage goes into the storage of the toner cartridges, as it is stated that they are relatively durable which comes with storage rarely being a problem. If this kind of scoring would be done for a product where storage is of higher importance this number will naturally be higher.

In Table 13, the CF280X process steps in most need of improvement (in relation to the remanufacturability) can be found. However, the process steps are not related to each other but to how many criteria that are fulfilled within each specific process step. The number of criteria correlating with the process step and attributes differ, as seen in Table 11, which results in a score that is not directly comparable between each process step, e.g., 50% in one step is not comparable to 50% in another step. Nevertheless, the scores could be used to identify the amount of improvement that could be achieved within each process step. This also explains why the reprocessing of attribute A5 displays 0%, since only one criterion was formulated here. Furthermore, this criterion was not a *must* criterion which explains why the toner cartridge is still remanufacturable despite the score 0% in this category.

7.1.5 MAR as a real-life application of EN45553:2020

After looking at both the methodology provided in the EU standard EN45553:2020, theory provided and the steps that felt most natural to take, one could argue that the EU standard is certainly useful. The steps provided are logical but because the methodology is described in a generic manner, it can be difficult and time consuming for the user to grasp. Since the standard is written to include all ERPs it can take quite some time to translate the steps into what is appropriate for the product in mind, in this case toner cartridges. In the creation of MAR these steps were generally followed with the exception of adding several sub-categories under each step. This shows the need for more specific research on the topic in line with this research. To encourage more manufacturers to try remanufacturing it is useful to provide more specified guidelines for other product categories. When using MAR the user is spared from translating the steps to the toner cartridge and can more efficiently start evaluating the remanufacturability of its product. Another benefit from using MAR is the adaption for increased understanding, more steps have been added and less formal language is used to lower the threshold for using the method. Another aspect that can be both positive and negative is the fact that the user still is given some room for interpretations and adjustments in MAR. The calculations in the last step are not thoroughly explained but the user must find their own way of weighing and scoring. If looking for a methodology that in detail explains what to do in every step MAR might be criticized for not being helpful enough. However, the freedom of shaping MAR into what a certain company needs is believed to also be one of its strengths.

The chosen toner cartridge, CF280X, was suggested as a representative and common toner cartridge model during the interview in the case study. According to Gustavsson (2020), the CF280X is easy to understand and well suited for remanufacturing. The model was also mentioned in the literature, confirming that CF280X could be seen as a common toner cartridge suited for remanufacturing. Furthermore, the criteria in the case study and MAR created to fit CF280X can be used for other toner cartridge models as well. Same goes with the scoring, MAR is created to fit other models and not just CF280X.

7.1.6 Improvement suggestions of MAR

One thing that needs further improvement is the usability of the last step of MAR and case study: the calculation. An excel sheet with calculations will accompany MAR but the calculations are far from obvious for a novel user. The user friendliness of the method needs to be improved to lower the threshold of evaluating the remanufacturability of a product. One suggestion is to create a light version of MAR to only cover the basics and does not require as much data collection and prior research. However, the reason for performing the case study in such a detailed manner is to make sure no aspect of remanufacturing is neglected. Many factors (also non-technical factors excluded from this research) make a difference and should be kept in mind by a manufacturing company. The coverage of this research makes the results more trustworthy. With that being said, efforts in future work can now be made on increasing the usability of the method to make sure the user receives something with large coverage but few risks of mistakes.

7.2 Project process

This part of the discussion covers how different factors might have had an impact on the process - whether it was positive or not and how a future study might benefit from considering these topics.

7.2.1 Impact of digital data collection

With the situation of Covid-19, to modify the data collection methods was necessary, even though it somewhat affected the result of the report, especially the time plan. A company visit at the manufacturing site had resulted in more understanding of the process and more efficient collection of data. The digital interview and lack of observation postponed the work for a couple of weeks. When the video of the remanufacturing process was received many questions were answered. If one performs this type of research again, physical observations are beneficial. With that being said, the quality of the results is believed to not have been affected. However, the fact that without the postponed time plan, the work could have proceeded further than in the current state remains.

Furthermore, the fact that people who know they are being observed and therefore behaves differently (van Boeijen et al., 2020), needs to be taken into account. The same phenomena can be transferred to videos. Scandi-Toner could easily decide what to show and what not to show before the process material was being sent. However, the fact that the process steps at Scandi-Toner corresponds well with the written literature on remanufacturing increases the trustworthiness of the video material in general. With that being said, if several companies' processes would have been observed, the projects results would rely less on the honesty of one company.

7.2.2 Size of Case Study

The interview and observations of this project were conducted solely at the company Scandi-Toner in Karlstad. Excluding other companies that remanufacture toner cartridges may have limited the research in some ways but does not necessarily have had a negative impact on the result. For example, the inclusion of several companies could have resulted in a deeper understanding of remanufacturing processes, toner cartridges and how it can differ in the execution. However, trying to fit in too much information within the time limit of the project could instead have resulted in a larger amount of data that the researchers perhaps would not have had time to analyze. Having more quantitative data, instead of the qualitative data received in this study, is rather a question of choices than ability.

Information that was gathered regarding the toner cartridge CF280X and the remanufacturing process could have been further confirmed and the generalization of the scoring method had probably been more viable if several companies had been included in the study. However, the delimitations were formulated as only including Scandi-Toner since the addition of several companies would not fit into the timeframe of this research. Thus, it is believed that it would be beneficial to study several companies remanufacturing toner cartridges in the future but within this study it was not feasible to implement.

This research involved interviews with one of the employees at Scandi-Toner. The interviewee was well versed in the subject and had great knowledge of both the remanufacturing process and the company. However, including interviews with several employees from Scandi-Toner could have been beneficial for the data collection and contributing to a broader understanding of difficulties with remanufacturing toner cartridges. For example, other employees may have other experiences and expertise on remanufacturing the CF280X, adding more aspects to the assessment. On the other hand, the interviewee in this research had been working at Scandi-Toner for several years and could contribute with all the essential aspects in the remanufacturing process for CF280X. Further details from other employees would likely not radically change the outcome of the research.

7.2.3 Impact of delimitations

The scope of the research did not include the non-technical aspect affecting the remanufacturability. The aim for this was to be able to create a method for assessing the remanufacturability, within the time limit and with the assets provided, that indicates how well suited the product is for remanufacturing. However, as the literature mentions, there are non-technical aspects that do affect the remanufacturability regarding e.g., costs and worth, but thus this is more of a subjective assessment it is not as easy to measure as the technical aspects. Within the case study, aspects such as time was mentioned as a part of the assessment if the toner cartridge were worth remanufacturing, however, this is something that could be transferred into technical aspect such as the number of different joints.

As previously mentioned, the study was also limited to data collection at one manufacturing company. If interviews and observations would have been possible at multiple companies, the generalization of the results would have been more trustworthy. Now, there is a possibility that the manufacturing steps, priorities, and ability to handle certain problems are different at other companies within the same business. The verification of MAR would also have been beneficial to perform at another company to confirm the usability of the steps. However, because of the years of experience in remanufacturing toner cartridges and the simplicity in the construction of the product, it is doubtful that the process would be remarkably different at another company compared to Scandi-Toner.

7.3 Contributions of findings

The following subchapter discusses how the findings from the study can aid in future research on the topic of remanufacturability and raise the possibility of value for other actors.

7.3.1 The contributions of case study results

The case study clearly indicates that assessment of remanufacturability of non-complex energy related products, like toner cartridges, can be conducted by using rather simple methods. To find improvement areas can be done rather quickly. Also, the way of weighing and calculating the criteria does not have to be performed in the same way for every user. The weighing and calculations in this case study could be used as inspiration in future work. One could argue that the results of the case study validate the relevancy of research on remanufacturability, and that both the methodology and results can be used as a point of reference for similar studies in the future.

7.3.2 The contributions of MAR

The structure of MAR was aimed at helping manufacturers who would either like to start remanufacturing products or are already manufacturing but want to evaluate the remanufacturability of models they do not currently process. By performing an assessment of remanufacturability in the presented case study, the researchers were hoping to make mistakes others will not have to make. Therefore, MAR was presented as a methodology to ease the process of evaluating the remanufacturability of a toner cartridge model. Because of the potential in the field of remanufacturing, MAR is also directed towards researchers who can continue develop assessments for other products and making MAR more efficient. Here MAR will act as a steppingstone for future research and something to build upon.

7.3.3 The contributions of design improvement suggestions

Since the independent remanufacturers cannot affect the design of the toner cartridges, one could claim that suggestions for design improvements are irrelevant. However, the design suggestions could also be used as an indication of how well suited a product is for manufacturing. If the product fulfills many of the design improvement suggestions, there is a clear indication of the product being suitable and that it would be easy to start with remanufacturing.

Furthermore, one could hope that it can be an eyeopener for OEMs when realizing how small changes in the product design can highly influence the profitability of remanufacturing. If these design guidelines are easy to follow it could lower the threshold for creating redesigns that are better suitable for remanufacturing. If independent remanufacturers can show how profitable this industry can be, OEMs might feel intrigued to get involved too and that is highly beneficial for remanufacturing and circular economy.

8 Conclusions

In this final chapter, the conclusions of the report, answers to the research questions and suggestions for future work are presented.

8.1 Summary

The benefits as well as the limitations with the used methodology is presented and summarized in this subchapter.

8.1.1 Benefits with the used methodology

The study follows the methodology for assessing the remanufacturability of energy-related products which was first described in EN45553:2020. This methodology is logical but described in such a way that it can be applied on a wide range of products. This made it time consuming for the project group as first-time users to apply on the intended product, which made the preparatory research thorough and comprehensive, leaving a reliable and well researched scoring as a result.

8.1.2 Limitations with the used methodology

A limiting factor with the study is the fact that it only considers the technological aspects of remanufacturing toner cartridges. In reality, remanufacturing is a complex subject which depends on a large number of factors. The remanufacturability of a product depends on, besides technological aspects, for example on the knowledge and experience of the staff, the economic input from the company and the supply and demand of toner cartridges. In order to make a complete assessment of the remanufacturability of a toner cartridge, these aspects should be considered as well.

Another limitation within the case study is the fact that the data collection was made entirely digital due to the Covid-19 pandemic. This might have influenced especially the process observations, as they were made by watching an instructional video filmed by employees at the manufacturing company. This might have influenced how accurately the process was portrayed. Further, the study was limited to solely observing the process at one toner cartridge remanufacturer. In future studies, data from several companies should be collected to further strengthen the results.

8.2 Answers to the research questions

This subchapter provides answers to the research questions of the project.

8.2.1 RQ1

The first aim of the study was to answer the question: "*How can the assessment methodology in EU standard EN45553:2020 be adapted to remanufacturing of toner cartridge CF280X?*"

The methodology presented in EN45553:2020 can be adapted to the specific toner cartridge model by gaining a deep understanding of the topic of remanufacturability and about the remanufacturing process of the cartridge. Further, in order to assess the remanufacturability of the product using the guidelines from the standard, the user needs to evaluate what parts of their process should be linked to what parts of the theory in the standard. The subjectivity of this part of the process should be considered when using the results from the assessment.

8.2.2 RQ2

One of the main goals for the study was to assess a way of calculating the remanufacturability of the specific toner cartridge. Therefore, the second research question was set to be: "*How can a score for assessing remanufacturability of toner cartridge CF280X be calculated?*"

The study finds that it is beneficial to conduct two types of assessments- one on whether a product is at all remanufacturable and one on how well suited it is for remanufacturing. This can be done by analyzing the product using criteria originating from the product attributes in the EU standard 45553:2020. The chosen criteria should have been deemed as relevant for remanufacturability of the product by the user. In this study, the criteria were divided into three sub-categories based on their importance for remanufacturability. The first sub-category consists of *must* fulfill-criteria and correspond to the assessment of at-all remanufacturability. The second and third sub-categories consists of *should* and *might* fulfill-criteria. These are part of the second type of assessment. Following the analysis of criteria, the assessment should consider how influential the individual criterion and process steps are on remanufacturing and apply weights to them accordingly.

Doing this, the study found that CF280X is remanufacturable using a binary score of either being or not being remanufacturable and has a remanufacturability score of 90%.

8.2.3 RQ3

The third research question was formulated as follows: "*With potential modifications, how can the assessment method be applied to similar toner cartridges*?".

The research within the project found that the factors which needs to be considered when working with giving a score on remanufacturability of toner cartridges varies a lot depending on the specific product in question. Rather than providing a concrete suggestion on what to consider and how to conduct a scoring of the remanufacturability of the product, the project presents a methodology, called MAR, on how to develop a scoring method for remanufacturability of toner cartridges. MAR provides suggestions on how to use existing information about remanufacturing, as well as the EN45553:2020, and apply the theory to the specific toner cartridge model. MAR is believed to, if subject to more research, be possible to be generalized so that the methodology is suitable to a larger variety of products in the future.

8.2.4 RQ4

The fourth and last research question reads: "*Which design guidelines are beneficial to implement to better enable remanufacturing of toner cartridges?".*

The case study along with gathered theory finds several areas of improvement of the specific toner cartridge CF280X, considering remanufacturing. The improvement suggestions are as follows:

1. Fewer parts in the design of the cartridge are beneficial. Each part that must be separated is a risk of damaging the product or adding valuable time to the disassembly/assembly process.
2. Large parts with wide openings are easier to access and clean.
3. Avoid non-reversible fasteners like glue to minimize damage when separating parts.
4. Small details in fragile materials should be kept to a minimum, e.g., protrusions should be kept to a minimum.
5. Create a design in a durable and cleanable material to enable additional loops of remanufacturing.
6. If chips and electronics are used in the cartridge, make sure there is a way to reset these, so they do not have to be replaced with every remanufacture.
7. Parts that are often drilled into today (e.g., the toner container) could be made accessible by creating a resealable opening or a shutter to eliminate the permanent damage drilling holes creates.
8. When determining how to arrange parts in the cartridge design, prioritize placement in a way to determine the condition of the component without disassembly if possible.

These guidelines are meant to aid designers to better enable remanufacturing of their toner cartridge.

8.3 Contributions of results

The study found that the results have several areas of contribution - both to further research but also to manufacturers who wants to start working with remanufacturing and to designers wishing to better the remanufacturability of their product. The results from the case study can be seen as validation of the relevancy of the research topic, while MAR can be used as a basis for further studies on how to apply the methodology presented in EN45553:2020 on real life cases. Furthermore, the presented design improvement suggestions can be relevant for designers and manufacturers who wishes to improve their products' remanufacturability.

8.4 Suggestions for future research

Here are suggestions for researchers who would like to continue studies in this field:

- The final remanufacturability score, presented as a percentage of remanufacturability, can be difficult to interpret without guidelines. Therefore, guidelines for evaluating if the received scoring is good or bad could be assessed in future research. These guidelines could either be set by the company conducting the scoring, be general for many companies remanufacturing the same product or be set for all energy-related products using MAR.

- The performed case study is the first verification of MAR. However, to increase the reliability of MAR, tests in the form of performing MAR at other companies, in other processes and on other toner cartridge models is needed. The results of the case study in this project can be used as inspiration for future work.

- One of the delimitations of this study is that non-technical factors like economy, market demand, company resources etcetera are excluded. However, the literature study shows how these factors can have a large impact on how remanufacturable a product can be for a certain company. It is suggested that future research should be made to include these non-technical factors in MAR as well to get an even more realistic scoring of the remanufacturability of a product.
- Today, MAR is accompanied by an extensive Excel sheet with many criteria and boxes to fill in. One suggestion is to increase the usability to lower the threshold of MAR and enable users to use the method without risking them doing it inaccurately.
- The research of this report is one adaptation of EN45553:2020 but more studies will have to be conducted in the future on both toner cartridges and in other product categories. If other adaptations are being made from the standard these cases can be compared to one another and find improvement areas of either the EU standard or the individual studies.
- The fact that OEMs are deliberately adapting the design of toner cartridges to complicate remanufacturing is a problem. The question of what it takes to inspire OEMs to the point where they start their own remanufacturing, or at least start to include more remanufacturing guidelines in their design, is also suggested as future research.

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Appendix 1 – Tables from the Literature study

Table 15. Examples of high-level remanufacturing guidelines listed by Iljomah et. al. (2007).

Process activities	Product/design characteristics		
	Material	**Assembly technique**	**Product structure**
Disassemble product	For components destined for reuse ensure that their materials are sufficiently durable to survive disassembly.	Use assembly methods that allow disassembly with-out damage to components.	Arrange components for ease of disassembly
			Reduce the total number of parts.
			Reduce complexity of disassembly, for example by standardizing fasteners.
	Ensure that fasteners´ material are similar or compatible to that of base material thus limiting opportunity of damage to parts during disassembly.		Use modular components thus reducing complexity of disassembly because types of assembly techniques are reduced.
			Arrange components so that separation joints are easily accessible and easily identifiable.
			Minimize the number of joints.
			Reduce/eliminate redundant parts.
			Simplify and standardize component fits.
			Ensure that all parts to be cleaned are easily accessed.
			Reduce/eliminate redundant parts.
Clean components	Use material that would survive cleaning process e.g. ensure that material melting point is higher than clean process temperature	Use assembly methods that allow disassembly at least to the point that internal components can be accessed for cleaning.	Arrange components so that all can be accessed for effective cleaning
			Ensure product surfaces are smooth and wear resistant.
	Limit the number of material types per part.		Reduce/eliminate redundant parts.
	Identify components requiring similar cleaning procedures and cleaning agents.		Structure to facilitate ease of upgrade of product.
			Arrange components for ease of access to parts prone to damage.
Remanufacture components (including test components)	Use materials that are at least durable enough to survive to refurbishment process.	Use assembly methods that would allow disassembly at least to the point that internal components and subsystems requiring.	Standardize parts.
	Use materials that do not prevent upgrade and rebuilding of the product.	Use assembly methods that do not prevent upgrade of product	Structure for ease in determining component condition
	Identify component material.	Use joining methods that allow disassembly at least to the point that internal components and subsystems requiring it can be accessed for testing before and after refurbishment.	Structure so testing is sequential, mirroring reassembly order.
		Incorporate fault tracking device.	Minimize the disassembly level required to effectively test components

			Standardize test procedures.
			Clearly identify component load limits. Tolerances and adjustments.
			Reduce structural complexity
			Identify components assembly sequence
			Reduce redundant parts.
Assemble product	Limit the number of different materials.	Identify components requiring similar assembly tools and techniques.	Standardize parts.
		Choose assembly methods that do not prohibit disassembly without damage to reusable components.	Structure for ease of access to short life and prone to break down parts.
		Use assembly methods that facilitate easy disassembly without damage to reusable components.	Use modular structure so that obsolesce occurs with components rather than with entire product.
		Apply design for assembly methods that do not prevent disassembly without damage to components	
		Reduce complexity of reassembly e.g. standardize fasteners.	

Appendix 2 – Technical drawings

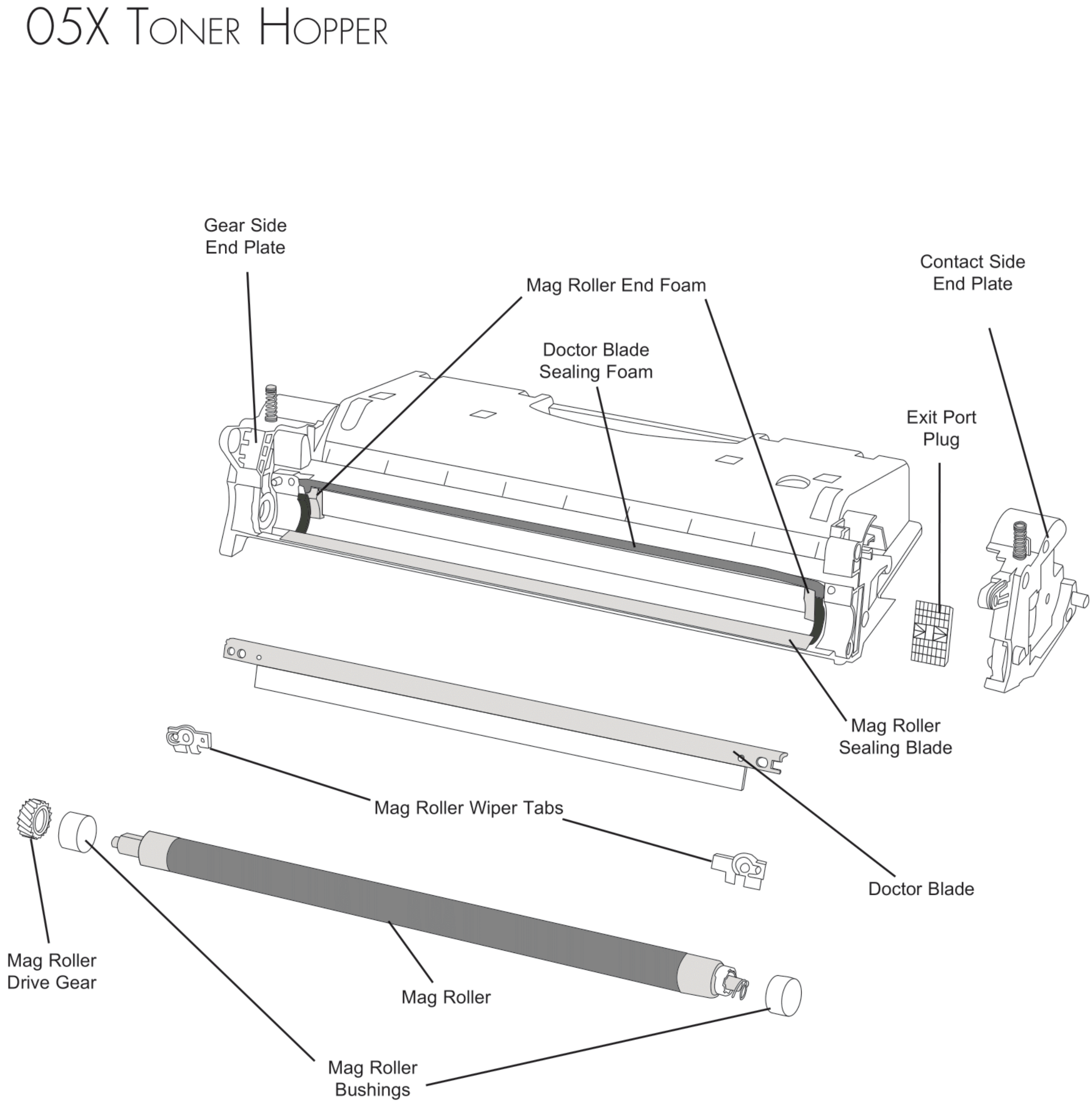

Figure 8. Toner Hopper components of HP CE505X (same as CF280X), taken from Static Control Components technical documentation (SCC, n.d)

Waste Bin

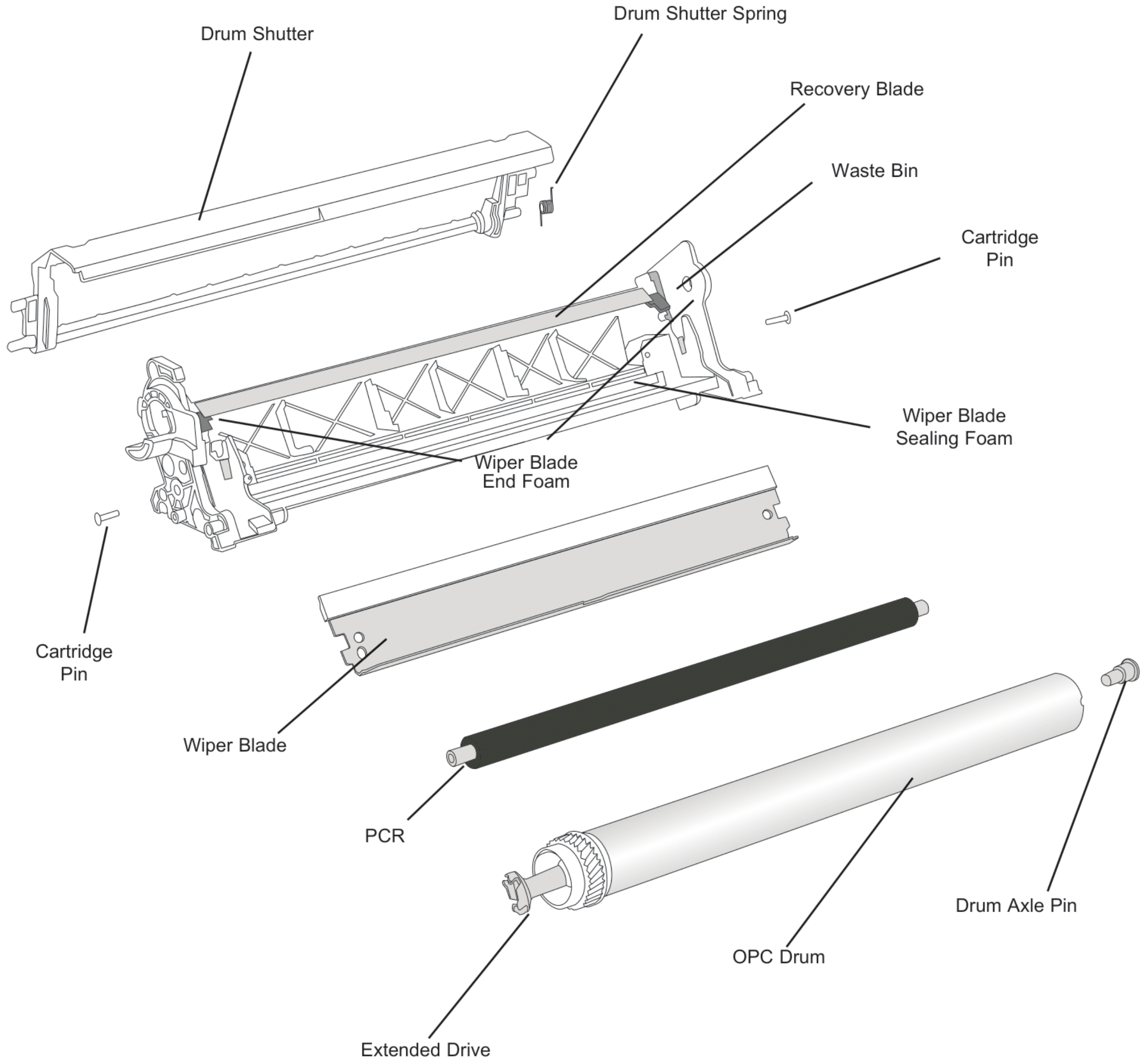

Figure 9. Waste bin components of HP CE505A (same as CF280X), taken from Static Control Components technical documentation (Static Control Components, n.d)

Appendix 3 – Interview questions

The original interview questions are presented below in its Swedish original version. An English translation follows directly after.

Del 1 - Bakgrund

Grundläggande frågor om vem personen är och vad den gör på Scandi-Toner.

- Är det okej att spela in för att komplettera anteckningarna i efterhand?
- Namn? Roll på Scandi-Toner?
    - Vad är det du gör (mer specifikt)?
    - Bakgrund?

Del 2 – Frågor om tonerkassetter och processen

- Berätta lite generellt om Scandi-Toner och processen.
    - Hur lång tid tar hela processen?
    - Vilka modeller av toner kassetter behandlar ni idag? Vi ser på hemsidan att ni nämner många olika märken och modeller.

- Hur bestämmer ni vilka nya modeller ni ska återtillverka?
    - Vem gör en sådan bedömning?
    - Vi kommer att titta på en specifik modell när vi tar fram vår metod. Har du något tips på en modell som en bra, och aktuell för er, för oss att välja?

- Vilka steg ingår i hela återtillverkningsprocessen från att cores/nya tonerkassetter kommer in - till att nya tonerkassetter skickas iväg?
    - Är det här samma för alla olika modeller?
    - Finns det några andra skillnader mellan modellerna?

- Hur skulle du introducera en ny kollega som ska arbeta i produktionen till sina arbetsuppgifter?

- Finns det någon kassett ni får in där du skulle reagera ”åh nej, inte en sådan här kassett”? Varför?

Frågor om varje steg:

- Inspektion
    - Vilken kunskap krävs för att utföra undersökningen för att se om tonerkassetten är återtillverkningsbar?
    - Går det att visa upp vad du tittar på i inspektionen?
    - Finns det någon designaspekt/del i tonerkassetten som försvårar inspektionen vid återtillverkningen?

- Demontering
  - Vilka metoder används? Vilka verktyg behövs?
  - Vilka typer av ihopsättningar används? Skruvar, lim etcetera?

- Rengöring
  - Vilka metoder används? Vilka verktyg används?
  - Vilka svårigheter finns?
  - Är det någon del som är svår att komma åt för rengöring?
  - Finns det någon designaspekt/del i tonerkassetten som försvårar rengöringen vid återtillverkningen?

- Bearbetning
  - Är det bara att fylla på ny toner?

- Montering
  - Hur går det till när ni sätter ihop delarna igen?
  - Hur går det till när tonerkassetterna monteras?
  - Finns det någon designaspekt/del i tonerkassetten som försvårar monteringen vid återtillverkningen?

- Testning
  - Vilka tester görs? Hur?

- Lagerföring
  - Hur förvaras de färdiga kassetterna innan de säljs?

Kan du beskriva lite mer om hur ni hanterar reservdelar? När skördar man dem?

Del 3 - Allmänna frågor:

- Upplever du problem med återtillverkningsprocessen som den ser ut idag?

- Är det något steg som tar extra lång tid eller är extra jobbigt?

- Har ni någon metod för att mäta återtillverkningsbarheten för inkomna tonerkasetter (cores)?
  - Vid intagning av nya; Hur mycket tid lägger ni på att lära er om konstruktion och ändra processen osv? Hur görs bedömningen?

- Om det skulle skapas en sådan metod – vad tror du är viktigast att ta med?
  - Tror du att det hade hjälpt er i er bedömning när ni får in nya modeller?

- Vilka designaspekter på tonerkassetterna skulle förenkla återtillverkningen om de ändrades?

- Vilket är det värsta tänkbara skicket av en toner kassett som kommer in till er? Vad krävs det för att ni helt ska döma ut en produkt?

Avslut:

- Tror att det finns någon annan på Scandi-Toner som är bra att vi pratar med om det här? Som skulle kanske svara annorlunda på de här frågorna.
- Finns det någon möjlighet att filma olika steg i produktionen som du skulle kunna skicka till oss i efterhand?
- Går det bra om vi återkommer till dig med fler frågor om vi kommer på några?

English translation:

Part 1 - Background

General questions about the interviewee.

- Is it fine for you if we record this interview?
- What is your name and position at Scandi-Toner?
    - What is it that you do, more specifically?
    - Could you tell us more about your background?

Part 2 – Questions about toner cartridges and the process.

- Would you tell us about Scandi-Toner and your remanufacturing process?
    - How much time does it take to perform the whole process?
    - Which toner cartridge models do you process today? We saw on you website that you mention quite many models.
- How do you determine on which models to remanufacture?
    - Who at the company makes such a decision?
    - We will focus on a specific toner cartridge model in the development of our project. Do you have any suggestions on suitable models?
- What steps are included in the remanufacturing process, from when new cores enter the building until the last phase of you sending them away again?
    - Are these steps the same for all cartridge models?
    - Are there any other differences between the cartridge models?
- How would you introduce a new colleague who is new to his/her tasks in production at Scandi-Toner?
- Imagine you pick up a cartridge and make a first inspection and you react ”oh no”. What does that cartridge look like?

Questions on each manufacturing step:

- Inspection
    - What previous knowledge is needed to perform an inspection to determine if a toner cartridge is remanufacturable?
    - Could you show us what you look at during the inspection?
    - Are there any design aspects of a toner cartridge that complicate during the inspection of remanufacturability?

- Dissasembly
    - Which methods are being used today?
    - Which tools are needed?
    - Which types of fasteners and attachment methods are being used? Screws, glue etc.?

- Cleaning
    - Which methods are being used today?
    - Which tools are needed?
    - Is there anything that is particularly difficult?
    - Are there any parts that are hard to reach in the purpose of cleaning?
    - Are there any design aspects of a toner cartridge that complicate the cleaning step?

- Reprocessing
    - Please describe the process, is it just refilling of toner?

- Assembly
    - Describe the process of assembly.
    - Are there any design aspects of a toner cartridge that complicate the assembly step?

- Testing
    - What tests are performed on the toner cartridge? How and why?

- Storage
    - How are the cartridges stored before they are shipped to a customer?

How do you collect and handle spare parts at Scandi-Toner?

Part 3 – General questions

- Have you acknowledged any problems with the remanufacturing process as it is today?

    - Are there any specific steps that is extra time consuming or difficult?

- Are you using any methods for assessing the remanufacturabilty of incoming cores in the production today?
    - If the incoming toner cartridge model is new, how much time do you spend reading up on the construction and adapting your own process?
    - How is that inspection preformed?
    - If there would be a method for determining the remanufacturability, what would you say is most important for the method to cover?

- Do you think such a method would be helpful to you in your work of assessing the remanufacturing new models?

- Are there any design changes you could think of which would make remanufacturing easier?

- Which is the worst possible condition of a toner cartridge sent to Scandi-Toner?
    - What would it take for you to reject a product?

Finishing questions

- Do you think we would benefit by talking to someone in another position at Scandi-Toner?

- Would it be possible for you to film the different manufacturing steps and send to us? Since physical observations is off the table.
- Would it be okey if we got back to you for follow up questions, if need be?

Appendix 4 – TC criteria

Case results

$$\beta_x = \frac{l}{l+m+n} = 0{,}47\,, \qquad \beta_y = \frac{m}{l+m+n} = 0{,}38, \qquad \beta_z = \frac{n}{l+m+n} = 0{,}16$$

Table 16. Compilation of case results. Tabel includes process steps and corresponding criteria and correlation attributs. It also inlcludes weather or not the CF280x Scandi-Toner example fulfills the criteria, and the corresponding score.

#	Process step	Criteria	Attribute	Core meets the criterion	Score
1	**Cleaning**	It **must** be possible to clean the exterior parts of products without damaging them.	5	Yes	0,017
		The unit **must** be able to be cleaned using available methods	1	Yes	0,017
2	**Inspection**	The product **must** be produced by an OEM	5	Yes	0,017
		To be remanufactured as a unit, the product **must** come from its first cycle of use. If not, it can only be used for spare parts.	5	Yes	0,017
		The company **must** have capacity and resources in order to remanufacture the product	1	Yes	0,017
		The company **must** have knowledge to remanufacture the product.	1	Yes	0,017
		The product **must** be in such a condition that it can be remanufactured.	1	Yes	0,017
		One **must** have access to all the parts which has to be examined in order to determine the overall condition of the unit.	3	Yes	0,017
3	**Storage**	One **must** be able to store the unit without damaging the core or its parts.	5	Yes	0,017
4	**Disassembly of core**	The unit **must** be able to be disassembled using available methods	4	Yes	0,017

		The unit **must** be able to be accessed using available methods	3	Yes	0,017
		A single operator **should** be able to disassemble the unit without assistance	4	Yes	0,017
		The disassembly of the product **should** need an appropriate number of tools	4	Yes	0,017
		The disassembly of the product **should** require a low number of fasteners to be loosened	4	Yes	0,017
		The product **should** use as few different kinds of fasteners as possible	4	No	0,000
		There **should** be indications on where and how to disassemble the product	2	No	0,000
		There **should** be standardized types of fasteners used in the construction	4	No	0,000
		Sensitive parts of the construction **might** be clearly indicated or noticeable	5	Yes	0,017
		There **might be** jigs available which can be used during disassembly	4	Yes	0,017
		There **might be** diagrams and/or manuals describing how to disassemble the product	2	Yes	0,017
5	**Disassembly of parts**	The parts **must** be able to be disassembled using available methods	4	Yes	0,017
		There **should** be indications on where and how to disassemble and access key parts	2	Yes	0,017
		There **might** be indications on where and how to disassemble the product	5	Yes	0,017
		The disassembly of the product **should** require a low number of fasteners to be loosened	4	Yes	0,017
		It **should** be possible to access key parts without having to make permanent changes to the design	5	No	0,000
		The disassembly of the product **should** require an appropriate number of tools	4	Yes	0,017

		The parts of the product **must** be able to be accessed using available methods	3	Yes	0,017
		The parts of the product **should** be able to be handled or accessed without difficulty because of their size, shape, weight or other factors	3	Yes	0,017
		There **might be** jigs or other equipment available which can be used during disassembly	4	Yes	0,017
		Sensitive parts of the construction **might** be clearly indicated or noticeable	5	Yes	0,017
6	**Inspection**	The product **must** be in such a condition that it can be remanufactured either as an entire unit, or as parts.	5	Yes	0,017
		One **must** have access to all the parts which has to be examined in order to determine the condition of the unit and its parts	3	Yes	0,017
7	**Cleaning**	The parts which need to be cleaned **must** be physically accessible	3	Yes	0,017
		The unit **must** be able to be cleaned using available methods	1	Yes	0,017
		The parts which are sensitive to cleaning **must** be able to be cleaned using suitable methods OR be detachable in order to enable cleaning of the unit	5	Yes	0,017
		There **might be** jigs o other equipment available which can be used during cleaning	5	Yes	0,017
8	**Reprocessing**	The parts which should be reprocessed or replaced **must** be accessible	3	Yes	0,017
		It **must** be possible to identify which parts will need reprocessing	1	Yes	0,017
		It **must** be possible to either replace or repair the parts which needs to be reprocessed	1	Yes	0,017
		It **should** be possible to reprocess the product without damaging it	5	No	0,000
9	**Assembly**	It **must** be possible to access and assemble the product and its parts using available and appropriate methods and fasteners	3	Yes	0,017

		It **must** be possible to assemble all parts of the product, regardless of handling in previous remanufacturing steps	5	Yes	0,017
		There **should** be indications on where and how to access and assemble the product	2	No	0,000
		The assembly of the product **should** require an appropriate number of tools	4	Yes	0,017
		The assembly of the product **should** require a low number of fasteners to be fastened in order to assemble the product.	4	Yes	0,017
		It **should** be possible to assemble the product without having to make permanent changes to its design	5	Yes	0,017
		The parts of the product **should** be able to be handled without difficulty because of their size, shape, weight or other factors	4	Yes	0,017
		The methods used in assembly **should** enable future remanufacturing of the product	4	Yes	0,017
		There **might be** diagrams and/or manuals describing how to access and assemble the product	2	Yes	0,017
		There **might be** jigs or other equipment available which can be used during disassembly	4	Yes	0,017
		Sensitive parts of the construction **might** be clearly indicated	5	Yes	0,017
10	**Testing**	The product **must** give the impression of being newly produced after remanufacturing	1	Yes	0,017
		It **must** be possible to ensure the quality of the final product by conducting a final test	1	Yes	0,017
		All parts of the product which need to be tested **must** be accessible	3	Yes	0,017
		The functionality of the product after reprocessing **must** be able to be tested using available methods	1	Yes	0,017
		It **should** be possible to test the functionality of the parts or modules without disassembling the product	3	Yes	0,017

		It **should** be possible to test the product without a risk of damaging it or its functionality	5	Yes	0,017
11	**Storage**	It **should** be possible to put the unit into storage without damaging any parts	5	Yes	0,017

Appendix 5 - Methodology for Assessment of Remanufacturability (MAR)

Introduction

This document is made as part of a student project on application of EN45553:2020 at Linköping University, conducted in 2020. The scoring and calculations which are described briefly in Step 5: Scoring were made using an excel sheet. For access to this file, which can be used as an example or base line for further development, please contact project group member Signe Svorén [svoren@me.com] or supervisor, Erik Sundin [erik.sundin@liu.se].

The intended reader

MAR is aimed to aid someone who wishes to, for some reason, find a score on the remanufacturability of a toner cartridge. This could be benefitial for companies working with remanufacturing, who wishes to find a way to decide whether or not a toner cartridge model is worth to remanufacture or not. A score could also aid designers who are working on either the development of entirely new toner cartridge models, or redesign of already existing ones. The designer might want a tool for comparing different design options or for evaluating how well suited the existing design is for remanufacturing.

Expected results

After conducting the steps suggested in this guide the practitioner can expect results in the form of a grading on the remanufacturability of the examined product and a rating of how well suited its process steps and current design are for remanufacturing.

What is remanufacturing?

Remanufacturing is a process in which products which have already been through one or more cycles of use are restored to the original (or even better) condition to make it available for another cycle of use. Remanufacturing could either be done by the company that originally manufactured the product or a subcontractor of that company, or by an individual remanufacturing company. The remanufacturing process can be divided into seven steps, where all steps are conducted either one or multiple times and in an arbitrary order in relation to each other. The seven steps are inspection, cleaning, disassembly, reprocessing, assembly, testing and storage.

The product attributes introduced in EN45553:2020

Below follows brief descriptions of the product attributes which are introduced in E45553:2020. A product attribute is an element in the assessment of the remanufacturability of the product and its parts and describes the product's ability to fulfill certain criteria. If a product attribute impacts the remanufacturability of the product, it should be considered in the remanufacturing process. For more thorough descriptions of the product attributes, see EN45553:2020 section 5.

A1: Ability to be identified / Diagnosis and analysis

The aim of this product attribute is to measure the ease of understanding the functionality of the product as well as how easy it is to determine the condition of the functionality. Included in this attribute is also if one can identify which parts will be needing reprocessing and which parts might need special care from the remanufacturer.

Often applicable to the following process steps: Inspection, testing, storage

A2: Ability to locate access points and fasteners

In order for a product to be remanufactured, it will have to be separated into smaller parts (disassembled). Attribute 2 examines how one is able to locate how and where to dismantle the product in question, i.e where access points and fasteners for key parts of the construction are and how it influences the remanufacturability of the product.

Often applicable to the following process steps: Disassembly, assembly

A3: Accessibility of parts / Accessibility of key parts

When the access points and fasteners have been identified, one must consider how easy it is to actually access the parts in each of the process steps. This attribute also includes the accessibility of the locators and fasteners. The questions asked within this attribute are specific to each process step.

Often applicable to the following process steps: Disassembly, cleaning, reprocessing, assembly, testing.

A4: Ability to disassemble/assemble / Ability to disassemble/assemble parts and product

When the key elements which are to be disassembled/assembled are located and their accessibility has been examined, they need to actually be separated from one another, and this attribute examines how easy that process is. It takes in a range of factors, from size and shape to number of operators and tools needed for conduction.

Often applicable to the following process steps: Disassembly, assembly

A5: Wear and damage resistance during remanufacturing

A key element for products to be remanufacturable is that they are able to withstand the wear and damage which might be caused by the remanufacturing process. This might be affected by the quality of the original product and the chosen remanufacturing methods and their impact on the materials and parts of the product.

Often applicable to the following process steps: All seven process steps (Inspection, Disassembly, cleaning, reprocessing, assembly, testing, storage)

The methodology

The following instructions describe the steps that are recommended for the user to follow when conducting an assessment of remanufacturability of one specific toner cartridge model:

Step 1: Data collection and identification of the remanufacturing process steps / order of conduction

Input data: A product for which remanufacturability is to be examined.
Useful data collection methods: Interviews and observations.
Output data: A step by step process list with short description of each step.

Procedure:

2. Gain knowledge about the remanufacturing process by either interviewing or conducting observations at the remanufacturer. This can be done either by interviewing remanufacturing staff and/or by observing the remanufacturing process live or via recordings. If the product has no official remanufacturing process available, it could either be simulated or represented by the remanufacturing process of a similar product.
3. Make a process tree showcasing the different process steps, see example below. Make sure to include all steps, even if some are conducted simultaneously. This process tree will be the output of step 1.

Table 17. An example of a generic remanufacturing process for a fictive product. As can be seen in this example, some of the seven general process steps which are always part of a remanufacturing process are conducted multiple times.

<table>
<tr><th colspan="2">REMANUFACTURING PROCESS OF A GENERIC TONER CARTRIDGE</th></tr>
<tr><td colspan="2">Cleaning of entire product</td></tr>
<tr><td colspan="2">Inspection of entire product</td></tr>
<tr><td colspan="2">Storage until requested by customer</td></tr>
<tr><td colspan="2">Disassembly into two components, A and B</td></tr>
<tr><td>Hopper</td><td>Waste bin</td></tr>
<tr><td>Cleaning and inspection</td><td>Cleaning and inspection</td></tr>
<tr><td>Reprocessing</td><td>Reprocessing</td></tr>
<tr><td>Reassembly</td><td>Reassembly</td></tr>
<tr><td>Cleaning</td><td>Cleaning</td></tr>
<tr><td colspan="2">Reassembly of part A and B</td></tr>
<tr><td colspan="2">Testing of complete remanufactured product</td></tr>
<tr><td colspan="2">Potentially improvements based on test results</td></tr>
<tr><td colspan="2">Storage until delivery</td></tr>
</table>

Step 2: Linking the process steps to the applicable product attributes

Input data: Output from Step 1 + descriptions of the product attributes (A1-A5) + Empty linking table
Output data: An overview of the link between the product attributes and process steps for the specific product.

Procedure:

2. Use the table in and fill in the *process steps* found in step 1.
3. Assess the relevancy for each *product attribute* on every *process step*, based on knowledge on the remanufacturing process and mark that link in the table.

Step 3: Formulation of suitable questions for each process step, based on the product attributes
Input data: Output from Step 2
Output data: A list of questions based on the product attributes, which need to be met by the product

Procedure:
Working with each process step separately, formulate questions which aim to collect data connected to the product attributes which were considered relevant for the current process step. Use the table which was filled in during Step 2 as well as the example assessment attached for reference.

Note:

- Think of the questions as check lists that should be able to be used to make sure all the data which is needed in order to assess the remanufacturability has been collected.
- Make sure to note what product attribute each question aims to provide information on.
- The same question can be asked multiple times in different process steps, if the information could have been changed during the previous steps.

Step 4: Translation from questions into criteria (including prioritization)
Input data: Output from Step 3
Output data: A list of criteria

Procedure:

3. Rephrase the questions formulated in Step 3, so that they are criteria which need to be met rather than questions. For example, the question "Is it possible to clean the unit using available methods?" can be rephrased as "The unit must be able to be cleaned using available methods".
4. After initial formulation, the criteria should be prioritized based on how significant they are for remanufacturability. There should be a distinction between criteria which are crucial for remanufacturability, and ones that are advantageous, but not crucial, if met. This will be important for the following steps.

Note:

- Make sure to note what product attribute each criterion aims to provide information on
- One way of differentiating the criteria is to formulate the crucial criteria as "must"-criteria (for example, "the unit must be able to be cleaned using available methods") and the advantageous, not crucial, criteria as "should" or "might" criteria (for example, "the unit should be able to be cleaned using available methods" or "the unit might be able to be cleaned using available methods)

Step 5: Scoring
Input data: Output from Step 4
Useful tools for gaining input data: Some type of software that can be used for mathematical calculations and formulas, for example Microsoft Excel.
Output data: Two types of assessment of the remanufacturability of the product in question. The first one assessing whether the product is at all remanufacturable and the second one assessing how well suited the product is for remanufacturing.

Procedure:
4. Using a software, create a way to evaluate the product by the criteria by confirming or denying that it has met the criterion.
5. Sum up the results for the criteria deemed crucial for remanufacturing. If the product fails to meet even one of these criteria, it cannot be remanufactured until it has been met.
6. Sum up the results for the rest of the criteria. The number of criteria met in total will give a scoring on how well suited the product is for remanufacturing.

Note:
- Make sure to evaluate the weight coefficients and adjust them according to the analyzed. These will influence scoring, based on what is presented in section 5.3.3.

Linking table for the identification of relevant product attributes for each process step.

Below follows the table which should be used in step 2: "Linking the process steps to the applicable product attributes". The highlighted boxes represent the general links between steps and attributes and could be used as a guide in the assessment.

PRODUCT ATTRIBUTE	**REMANUFACTURING PROCESS STEP** *Here, you should fill in the process steps which were found in step 1 of the method. This table shows the seven steps (in an arbitrary order) and the general links between the steps and product attributes. This could be used as a guideline.*						
	Inspection	Disassembly	Cleaning	Reprocessing	Assembly	Testing	Storage
A1: Ability to be identified							
A2: Ability to locate access points and fasteners							
A3: Accessibility of parts							
A4: Ability to disassemble/assemble							
A5: Wear and damage resistance during remanufacturing							