KTH ROYAL INSTITUTE
OF TECHNOLOGY

Degree Project in Innovation Management and Product Development

Second cycle 30 credits

Design for Recycling

Guidelines for Increased Recycling Efficiency and Recovery Rate of Materials

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Stockholm, Sweden 2022

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Master of Science Thesis TRITA-ITM-EX 2022:330
KTH Industrial Engineering and Management
Machine Design
SE-100 44 STOCKHOLM

Examensarbete TRITA-ITM-EX 2022:330		
KTH Industriell teknik och management	**Design för återvinning - Riktlinjer för ökad återvinnings effektivitet och återvinningsgrad av material**	
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Sammanfattning

Tillverkningsindustrin står idag framför ett snabbt växande problem, nämligen den ökande mängden av elektroniskt avfall. På grund av den snabbt utvecklande teknologin så har innovations cyklerna förkortats och efterfrågan på olika elektroniska produkter ökat. Denna utveckling kräver allt mer avancerade materialkombinationer och sammansättningar för att möta både produkt- och kundkrav, vilket samtidigt leder till att produkter blir allt svårare att återvinna.

Ericsson är ett av världens största företag inom tillverkning och försäljning utav telecom utrustning och vill i större utsträckning kartlägga hur deras produkter återvinns, samt hur deras produkter bör designas för att underlätta återvinningsprocessen. I dagsläget har Ericsson ett dokument från 2004 med design riktlinjer med ett brett fokus på miljö. Syftet med detta examensarbete har varit att utveckla dessa riktlinjer, fast med ett fokus på när produkten nått slutet på sin livslängd och ska återvinnas. Detta har genomförts genom en initial insamling av data genom en litteraturstudie gällande designriktlinjer för återvinning. Dessa riktlinjer har utvärderats med en empirisk studie, där både kvalitativ och kvantitativ data har insamlats, analyserats och sammanställts. Störst fokus har legat på att diskutera med experter inom återvinning för att få en bra förståelse vad som är viktigt för att deras process ska fungera så effektivt som möjligt. Slutligen genomfördes ett test där tre produkter utvärderades med de slutliga riktlinjerna för att identifiera förbättringsområden.

Detta examensarbete har resulterat i 30 design riktlinjer med fokus på att öka effektiviteten av återvinningsprocessen av Ericssons produkter. Dessa riktlinjer berör tre olika områden: Material och material kombinationer, Fästelement och kopplingar samt Etiketter och markeringar. Det rekommenderas att dessa riktlinjer implementeras så tidigt som möjligt i Ericssons produktutvecklingsprocess för att få störst inverkan på den slutliga designen för nya produkter.

Nyckelord: *design för återvinning, elektroniskt avfall, cirkulär ekonomi, återvinningsbarhet*

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Abstract

The manufacturing industry faces a rapidly growing problem which is the increased stream of electronic waste. Due to the fast evolving technology, the innovation cycles have been shortened and the demand for various electronic products has increased. This development requires increasingly advanced material combinations and assemblies to meet both product and customer requirements, which at the same time leads to products becoming more difficult to recycle.

Ericsson is one of the world's largest companies in manufacturing and sales of telecom equipment and wants to gain knowledge in how their products are recycled, and how their products should be designed to facilitate the recycling process. As of today, Ericsson has a document from 2004 with design guidelines with a broad focus on the environment. The purpose of this master thesis has been to develop these guidelines, but with a focus on when the product has reached its end of life and is to be recycled. This has been done through an initial collection of secondary data from the literature regarding design for recycling guidelines. These guidelines have been evaluated using a mixed method, where both qualitative and quantitative data have been collected, analyzed and compiled. The biggest focus has been on discussing with recycling experts to get a deeper understanding of what is important for their process to work as efficiently as possible. Finally, a product evaluation has been performed where 3 products have been evaluated against the final set of guidelines to identify areas for improvement.

This thesis has provided 30 design guidelines with a focus on increasing the efficiency of the recycling process of Ericsson's products. These guidelines cover 3 different areas: Material and material combinations, Fasteners and connectors, and Labels and markings. It is recommended that these guidelines should be implemented as early as possible in Ericsson's product development process to have the greatest impact on the final design of new products.

Keywords: *design for recycling, electronic waste, circular economy, recyclability*

FOREWORD

This Master Thesis has been carried out as a part of the Master´s Programme Innovation Management and Product Development at KTH Royal Institute of Technology in Stockholm. The project was carried out in collaboration with Ericsson at the mechanical design department in Kista.

We would like to thank our industrial supervisor at Ericsson, Ulf Ahlberg, for your guidance, input and support throughout the project. We would also like to thank all respondents who have contributed with their knowledge to this project. Lastly, we would like to thank our supervisor at KTH, Johan Arekrans, for your support and continuous feedback during this project.

Linn Thureborn & Emma Yvell

Stockholm, June 2022

NOMENCLATURE

Abbreviations

ABS	Acrylonitrile butadiene styrene
BFR	Brominated Flame Retardants
CE	Circular Economy
DFA	Design for Assembly
DFAA	Design for Automated Assembly
DFD	Design for Disassembly
DfE	Design for Environment
DfR	Design for Recycling
EEE	Electrical and Electronic Equipment
E-Waste	Electronic and Electrical Waste
HIPS	High Impact Polystyrene
HRC	Hardness Rockwell Cone
MABS	Methyl Methacrylate Acrylonitrile Butadiene Styrene
PA	Polyamide
PC	Polycarbonates
PCB	Printed Circuit Board
PE	Polyethylene
PP	Polypropylene
PS	Polystyrene
REACH	Registration, Evaluation, Authorisation and Restriction of Chemicals
RoHS	Reduction of the use of certain Hazardous Substances
SVHC	Substances of Very High Concern
WEEE	Waste from Electrical and Electronic Equipment

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1 INTRODUCTION

In this chapter, a background to the study is presented. The purpose, aim and objectives are described as well as the delimitations that are set for the study.

1.1 Background

Today, electronic and electrical waste (e-waste) is the number one fast growing waste stream in the world and has an estimated growth rate between 3% to 5% per year (Cucchiella et. al., 2015; S. Shittu, D. Williams & J. Shaw, 2020). According to N. Perkins et. al. (2014), there are multiple factors that contribute to the increased amount of e-waste; consumer demands as well as short innovation cycles that contribute to unnecessary purchases. E-waste is classed as hazardous waste, which means it has a negative impact on both environment and health. It is therefore sorted out from other waste and is handled separately (Tiseo, 2021). The majority of e-waste is unfortunately recycled under unregulated environments that puts recycle workers in an toxic, unethical work environment. Some E-waste also contains various valuable materials that make them attractive to recycle, rather than put it in landfill because the metals have an economic value for recyclers (N. Perkins et. al., 2014).

The digitalization and automatization contributes to higher e-waste within trade and industry which creates a great demand for recycling possibilities. A global problem that is connected to the increased demand for electrical products, is the growing demand for raw materials (Li, He & Zeng, 2017). Some raw materials are difficult to extract in the volume that is needed today. Concerns regarding future limitations on manufacturing due to future lack of the rare earth metals have been lifted. With a functional recycling process, both natural resources and energy can be saved compared to when virgin material is used (STENA Recycling, n.d.).

A large amount of energy is required to extract and produce new virgin material. The energy required for the recycling of materials is a few percent compared to when the process begins at the mine (El-Kretsen, 2018). The fewer and cleaner materials that electronic products consist of, the easier the recycling process will be, and the outcome of the recycled material will be of higher quality. The recycling industry has developed a recycling process for e-waste that is performed by crushing and grinding the components. Thereafter, the different materials are being sorted out through optics, magnets, density or manually by hand (El-Kretsen, 2018).

The European Commission has developed directives with the aim to contribute to sustainable production, consumption and waste management of electrical and electronic equipment (European Commission, n.d. a). Directives that are highly relevant for electrical and electronic equipment are RoHs, Ecodesign, WEEE, REACH and Waste Framework. Apart from these directives, anyone that puts electrical equipment on the market is defined as a producer and has therefore a producer responsibility. Among other responsibilities, this includes a responsibility to take care of the equipment when it becomes waste. Each year it is also required for the producer to report how much equipment that has been placed on the market, and how much that has been collected as waste (Naturvårdsverket, n.d.).

Design for recycling (DfR) is a strategy aiming to reduce product life cycle environmental impact. Its meaning is to design products that are easier to recycle at their end-of-life phase (Maris et. al., 2014). According to the European Commission (2021), 80% of the environmental impact related to a product is determined during the design stage. With this in mind, there is no question about how important the design phase of a product actually is. Circular economy (CE) is a concept of economic models where the aim is to increase the lifetime of products and used materials by putting them into closed loop cycles. This is done by repairing, refurbishing etc. before the product is to be recycled in order to close the loop. This is a more sustainable flow in comparison to the linear flow, where products get produced, used and dumped. The first step in CE is to design products that can easily be upgraded and repaired (Naturskyddsföreningen, n.d.). Another aspect of the CE is design for recyclability, with the purpose to put used material in a closed loop for as long as possible (C. den Hollander, A. Bakker & Hultink, 2017).

1.2 Purpose

The purpose of this thesis project is to provide guidelines on how Ericssons radio products should be designed to enable an efficient recycling process and thereby increase the recycling rate of the materials used. The analysis will focus on Ericssons products within the radio system portfolio and how they undergo the recycling process. However, the guidelines will be applicable to all Ericsson products. The guidelines will be based on a literature study and further validated with recyclers opinions on what they see as critical in the recycling process.

The main objectives of this thesis project are:

- Investigate the current content and usage of the Design for Environment (DfE) dokument at Ericsson
- Examine DfR guidelines in the literature suitable for Electrical and Electronic Equipment (EEE)
- Evaluate selected guidelines from the literature together with recyclers' perspectives to provide a set of suitable guidelines for Ericsson's radio system products
- Provide recommendations on how the guidelines should be used and implemented in the product development process
- Examine how a set of Ericsson's radio system's products currently performs against the guidelines

1.3 Delimitations

The project will focus and optimize for current processes and methods used for e-waste recycling which the product would undergo when they end up at an e-waste recycler. More specifically the processes that Ericssons products undergo when they go through Ericssons take back program. Hence, the project will not consider other possible end of life treatments such as informal recycling or landfill, where we do not have any ability to influence. The project will also not examine other strategies within CE such as reuse and remanufacturing. Aspects that are regulated by law will not be included in the guidelines. Since the guidelines are to act as recommendations, it clashes with statutory rules that are instead requirements.

2 FRAME OF REFERENCE

In this chapter, background is presented as a foundation to the methodology, result and discussion for the study. It begins by presenting background to problems regarding e-waste and describes the associated recycling processes. Following it presents different legislations regarding handling of e-waste and ends by presenting design strategies linked to recycling and a short description of Ericssons product development process.

2.1 E-Waste and its impact

Electronic products are today something that is common and necessary in everyday life for the average consumer. Unfortunately, due to the large increase in digitization and electronic products, we now have a major global problem. E-waste is now the fastest growing waste stream in the world, and is currently growing with 3-5% per year (Cucchiella et. al., 2015; S. Shittu, D. Williams & J. Shaw, 2020). This has further increased pressure on recycling companies but also on various legislations (read more about legislations in section 2.3). The major economic driver for recycling e-waste is from the recovery of various precious metals (Cui & Zhang, 2008). But as products get more advanced and sometimes also smaller, recyclers are now struggling due to lower concentrations of valuable metals in e-waste (Parajuly et al., 2019).

E-waste usually contains various valuable metals, amongst gold, silver, copper, platinum and palladium (Namias, 2013). Extraction of raw metals requires significantly higher energy usage and emits more carbon dioxide compared to when recycled metals are being used. Unfortunately according to Kaya (2018), the e-waste recovery amount is only 20% of the produced products due to large quantities of improper management, which further contributes to global warming. If the materials in e-waste are not recycled properly, these can not replace primary raw materials and thereby reduce greenhouse gas emissions from extraction and refinement of primary raw material (Forti et al., 2020).

When it comes to regulated and controlled recycling, the most critical phase is the disassembly process; as it is a major cost when recycling e-waste. However, it has a possibility to be reduced through principles such as design for disassembly (Hester & Harrison, 2008). According to (Tansel, 2017) it is necessary to design high tech products for ease of disassembly to enable the material recovery process to be feasible.

2.2 The processes of e-waste recycling

Controlled recycling of e-waste typically consists of two common steps. The first step is pre-processing that includes dismantling, shredding and mechanical separation. The second step is end-processing where the separated material undergoes processes that include pyro/hydro/bio metallurgy treatments (Kumar, Holuszko & Espinosa, 2017). Another common end-process that serves as an alternative method for pyro/hydro metallurgy is electrometallurgy (Murugappan & Karthikeyan, 2021).

2.2.1 Pre-processing

The pre-processing steps vary a bit at different recycling companies. However, there are some steps that are common in the process of handling electrical waste; these steps are dismantling, shredding and mechanical separation. The first step in e-waste treatment is dismantling to separate hazardous components as well as valuable components such as printed circuit boards (PCB) that are traded and sent to specialized metallurgical treatment facilities (Salhofer, 2017). These components are dismantled to make the recovery process more efficient. Some of the components are in need of special treatment and not suitable for the next step in the process which is shredding. Shredding is the process where products, after the dismantling step, are grinded into small pieces and allow for further sorting of materials mechanically (Hester & Harrison, 2008). The final step in pre-processing is mechanical separation to separate various material streams from the shredded material. This process consists of several steps after each other. To remove ferromagnetic materials such as iron, steel and rare earth metals it is common to use magnetic separation. Materials such as copper, gold- and silver can be separated using density separators such as air tables, air cyclones and centrifugal separators. Aluminum is often separated using eddy current separators. Different kinds of plastic are often separated using infrared sensors and optical sensors can be used to separate glass (Kumar, Holuszko & Espinosa, 2017). After these steps, the material is separated and prepared for sale to companies working with end-processing treatments.

2.2.2 End-processing

Metallurgical processes are used to further upgrade and refine the metal containing fractions. There are two common processes for this, pyrometallurgical processes where metals are melted and hydrometallurgical processes where metals are dissolved. In pyrometallurgical processes the crushed material fractions are burned in a molten bath or a furnace to remove plastic that was not separated in the pre-processing. During this stage metals such as iron, lead, zinc are converted into oxides that further become fixed within a silica based slag. The remaining melt that mostly contains copper and other metals such as silver, gold, palladium and nickel are further refined (Naturvårdsverket, 2011). Hydro-metallurgical methods are based on the use of various leaching agents in aqueous solutions, such as strong acids and bases (Cui & Zhang, 2008). The main advantages with this method are low investments and the high recovery rate of metals (Yazici & Deveci, 2014). Biohydrometallurgy, a branch of hydrometallurgy, is a process that utilizes microorganisms, such as bacteria, fungi and archaea to facilitate the extraction and recovery of materials from waste in an aqueous environment (Kaksonen et al., 2018). This process is supposed to be green and eco-friendly. However, the method is still in an early phase of development due to its slow mechanism (Murugappan & Karthikeyan, 2021).

Plastics on the other hand are more complex materials consisting of numerous polymer blends and additives making the recycling process very difficult to handle. Hence, a majority of the e-waste plastics are not recycled, a large part goes directly to combustion to generate energy. Another large part, as mentioned earlier, is following the metal fraction to the smelter and acts as fuel in that process. The remaining plastics that can be recycled undergo processes such as melting, molding and extrusion so that they can be remanufactured into new plastic parts or products (Naturvårdsverket, 2011).

2.3 Existing legislation of electronic products

To provide recommendations on DfR it is important to understand the current legislations of electronic products. The following sections describe legislations regarding waste, hazardous substances, chemicals and responsibilities for the producer of electronic products. Figure 1 illustrates a timeline of when the directives described below came into force.

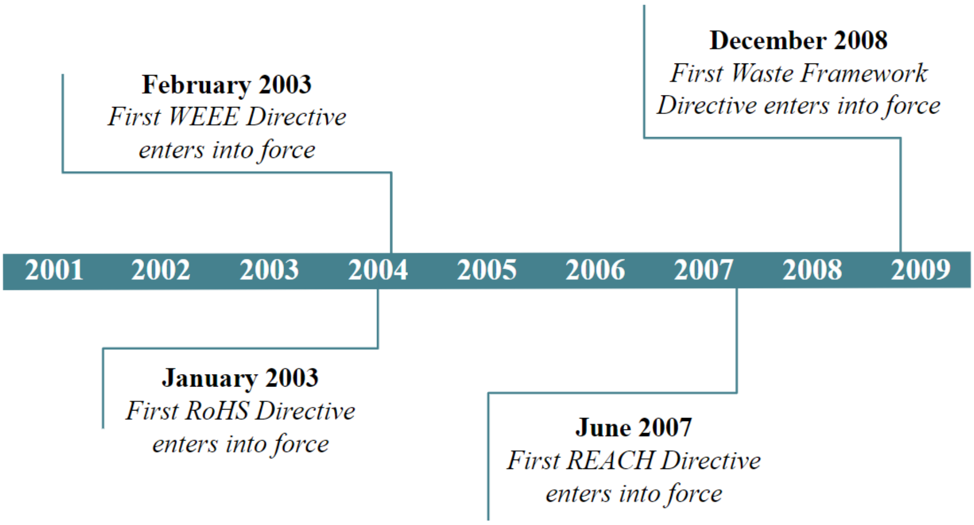

Figure 1. Timeline of when directives came into force.

2.3.1 RoHS Directive

Restriction of the use of certain Hazardous Substances (RoHS) directive was developed and first entered into force 2003 with the purpose of replacing and restricting the use of hazardous substances that poses risks for health and the environment. The directive also improves the possibility of profitable and sustainable material recycling from electronic waste. It is continuously evaluated whether more substances in various categories should be restricted (Kemikalieinspektionen, 2022). Currently the directive restricts the use of 10 substances including heavy metals, flame retardants or plasticizers: lead, cadmium, mercury, hexavalent chromium, polybrominated biphenyls (PBB) and polybrominated diphenyl ethers (PBDE), bis(2-ethylhexyl) phthalate (DEHP), butyl benzyl phthalate (BBP), dibutyl phthalate (DBP) and diisobutyl phthalate (DIBP) (European Commission, n.d. b).

2.3.2 WEEE Directive

Waste from Electrical and Electronic Equipment (WEEE) directive aims to contribute to sustainable production and consumption of electrical and electronic equipment. The directive addresses environmental and other related issues caused by the growing e-waste streams in the EU. Improvements of collection, treatment and recycling of WEEE can improve sustainable production and consumption, increase resource efficiency and contribute to a circular economy. The directive requires separate collection and proper treatment of WEEE which contribute to efficient retrieval of secondary raw materials through re-use, recycling and other forms of recovery (European Commission, n.d. c).

2.3.3 REACH Directive

Registration, Evaluation, Authorisation and Restriction of Chemicals (REACH) was entered into force 2007 to improve the protection of human health and the environment from the risks posed by chemicals. Manufacturers are responsible for making an assessment of possible risks with substances they use in their products. Companies must register this information in Echa, the European Chemicals Agency, and show that the substances can be safely handled and what potential risks that are involved for the user. The most important goal with REACH is to reduce the use of these substances of very high concern (SVHC), the EU's list of hazardous substances, and gradually replace them with less hazardous substances (Kemikalieinspektionen, 2021).

2.3.4 Waste Framework Directive

The waste framework directive provides waste management principles and definitions of waste, recycling and recovery. The waste management principles require that waste should be managed without risking human health or harming the environment. Water, air, soil, plants and animals should not be exposed for risks in relation to waste management. The 5-step "waste hierarchy" illustrated in Figure 2 is the foundation for EU waste management as it proposes an specific order for managing and disposing waste. The preferred option is to prevent waste from emerging and sending waste to landfill is the least preferred option (European Commission, n.d. d).

Figure 2. Illustration of the waste hierarchy (European Commission, n.d. d).

2.3.5 Extended producer responsibility for electrical equipment

Producer responsibility applies to anyone who places electrical and electronic equipment on the Swedish market. Producers are obligated to cover the management activities of returned products when they become waste. This management process should ensure that the waste is transported, pretreated, reused, recycled, energy recovered or managed in other acceptable manner. Producers are also obligated to, within one year after commenced sale, provide information for waste management operators regarding the product's content (Naturvårdsverket, n.d.).

2.4 Material - Change, challenges and combinations

The following sections highlight challenges related to material supply and the importance of using secondary raw material to mitigate these challenges. The section also covers how different material combinations are affecting the recycling processes.

2.4.1 Critical raw materials

As of today, 30 raw materials are classified as critical for our society and industry by the European Commission, see Figure 3. To be classified as a critical material there are two main criterias that are considered; its economic importance for the European industry and its risk of interruption in the supply to Europe. The growing demand for critical raw materials cannot be met without recycling and increasing the use of secondary raw materials. It is projected that it will take until 2100 before secondary raw materials can account for at least half of the amount of rare earth metals that the world will need (SGU, 2021).

antimony	baryte	bauxite	beryllium	bismuth	borate
cobalt	coking coal	fluorspar	gallium	germanium	hafnium
heavy rare earth element	indium	light rare earth element	lithium	magnesium	natural graphite
natural rubber	niobium	phosphate rock	phosphorus	platinum group metals	scandium
silicon metal	strontium	tantalum	titanium	tungsten	vanadium

Figure 3. Materials classified as critical for society and industry by the European Commission (SGU, 2021).

2.4.2 Challenges and opportunities regarding aluminum

The aluminum industry faces many challenges related to sustainability and the magnitude of these challenges is significant. The primary aluminum production globally may need to increase 25-30 million tons per year by 2050 in order to meet the United Nations Sustainable Development Goals according to an estimation done by the International Aluminum Institute. This means that today's challenges within the industry will continue to intensify, partly a need for ethical and sustainable mining and a need for smelters and refineries to shift towards low carbon energy mixes to reduce the greenhouse gas emissions (Wong, Kvithyld & Peng, 2020).

Today, Ericssons products contain a large proportion of aluminum. On the bright side, there are great opportunities with the material. However, it requires that sorting during the recycling is efficient. Aluminum is 100% recyclable without losing its original properties and it is estimated that 75% of all aluminum ever produced is still in use. The recycling process of aluminum only consumes 5% of the energy needed for primary production (Svenskt Aluminium, n.d.). The key stage to optimize the quality of recycled aluminum alloys is the sorting process. Hence, a closed loop recycling would enable to reduce the refining problems by transforming scrap of an aluminum alloy to secondary raw material of the same aluminum alloy (Capuzzi & Timelli, 2018).

2.5 Circular economy and design strategies

The possibilities of recycling different materials or products are mainly determined during the design phase. In this section, a quick introduction to circular economy and the concept's connection to recycling will be presented. Also a few different types of design strategies that are linked to the impact of a products' ability to be recycled are also presented.

2.5.1 The concept of Circular Economy

CE is a concept of economic models where the aim is to increase the lifetime of products and used materials by putting them into closed loop cycles. In the traditional, linear economic model, products are produced, used and dumped. This model relies on cheap energy and materials that are easy to access, and products are manufactured to have a certain, limited lifespan to increase sales for companies (European Parliament, 2015a). CE on the other hand builds upon a more sustainable flow where products get repaired, refurbished and recycled etc. to extend the life cycle. By preserving the value of materials, products and resources, various industries can increase cost savings (Bowles, Abbott & McIvor, 2021). But in order to make cost savings through CE possible, well developed product designs must be applied to be able to minimize waste at end of life (Munck-Kampmann, Werther & Holm Christensen, 2018).

A well-designed product sets the standard for how long a product's life cycle can be, but it does not end there. The design of a product is incredibly crucial when it comes to the final stage of its life, the recycling stage (Fifield & Medkova, 2016). An important part of CE is to feed back material into the economy (Munck-Kampmann, Werther & Holm Christensen, 2018), and recycling is the way to do it, see Figure 4 for an illustration of CE. In order to minimize waste, the recycling process must be effective and extract as much secondary raw material as possible (Fifield & Medkova, 2016). By implementing DfR strategies in the early design phase of a product can speed up the recycling process and make it more effective.

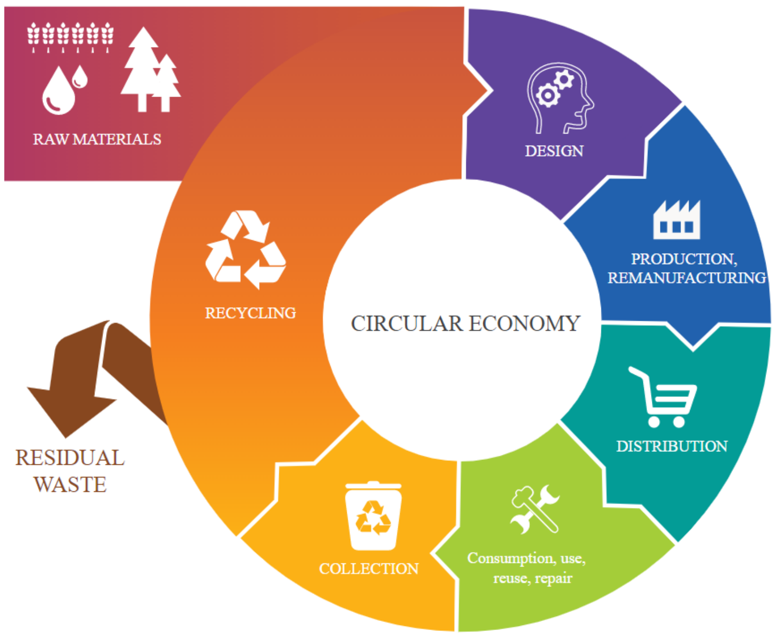

Figure 4. Illustration of Circular Economy (European Parliament, 2015b).

2.5.2 Design for assembly

Design for assembly (DFA) is a collection of different methods that help designers make better design decisions in order to reduce the production cost (Roulet-Dubonnet, Sandøy & Schulte, 2018). The purpose of DFA is to create products and associated manufacturing processes that are more efficient and productive. Products that are designed with DFA in mind take a shorter time to assemble and therefore reduce the production cost. A product can often be simplified by minimizing the amount of different components and assembly configurations to what only is needed (Velling, 2021). This reduces the span for risk of failure in the assembly process, since there are less operations needed to assemble the product. DFA can also help with a products' ability to be serviced and ease of maintenance in some cases (Tatikonda, 1994). However, there are assembly methods that are easy to assemble such as glue and snapfits, but these can be hard to separate without destroying the concerned components.

As the time passes by, new technologies develop and the manufacturing processes undergo a change and upscale towards automatisation. This has put DFA under change, creating and developing design for automated assembly (DFAA), where the aim is to minimize manual labor (Eskilander, 2001). An advantage is that products that are designed for automated assembly are still easy to assemble manually.

DFA and DFAA are strategies that are most often prioritized in the design phase of a product, precisely because these are directly linked to the production cost (O. Molloy, E.A. Warman & S. Tilley, 2012). An important aspect to keep in mind is that DFA and DFAA do not always facilitate the process when the product is to be recycled. The assemblies of some product modules do not have to affect when a product is in need of repair (as an entire module is usually replaced), but is instead critical for when all materials in the module are to be separated. It is important that companies not only think about how a product should be designed for production, but should also design products that are easy to disassemble. If done right, the materials can be easily separated at the product's end of life.

2.5.3 Design for disassembly

Before a used product reaches the recycling processes, a disassembly of the product is required. The more a product can be separated into smaller parts, the more of the used materials can be recovered through the following recycling processes (Soh, Nee & Ong, 2015). The disassembly process is usually manually performed, and requires manpower to be implemented which is directly linked to cost for labor. One way to decrease cost for disassembly is to design for disassembly.

Design for disassembly (DFD) provides a basis of a few guidelines, see Table 1, for designers to keep in mind in the designing phase of a product.

Table 1. DFD Guidelines (Dowie & Simon, 1994).

DFD Guidelines	Justifications
Minimize number of fasteners	Most assembly time is spent on fastener removal
Minimize the number of fasteners removal tools required	Changing tools cost time
Fasteners should be easy to remove	Saves time during disassembly
Fastenings points should be easy to access	Awkward movements slow down disassembly process

The most expensive part of recycling is the collection and disassembly of products (King, 2021). By applying DFD guidelines during the design phase, the time it takes to disassemble a product can be shortened, which then leads to reduced costs. It is important to understand during the design phase that it is not just a material that is going to be recycled, but it applies to an entire product. A product that can be easily disassembled, i.e. the product's components are not glued or pressed together for example, makes them better suited for reuse and recycling.

2.5.4 Design for recycling

DfR is something that often comes into the "shadow mouth" during the design phase for many product manufacturers. The reason for this is that other design strategies tend to be prioritized. DFA and DFAA are the design strategies that are most often prioritized, as these are directly linked to the production costs of a product (Nissen, 2019). DfR is a design strategy that aims to design products based on facilitating the recycling process and maximizing the outcome from it so that as much material as possible can be reused (Leal et al., 2020).

DfR includes some different types of requirements. A product designed from DfR should be easy to disassemble, and the different parts should be of the same material in order to prevent contamination when it is recycled (an example of this is that parts of copper and iron should be easy to separate) (Hassiotis, 2015). However, more alloys are used, where different metals are fused together, due to specific material properties in certain types of products. These alloys affect the outcome of recycling, and the secondary materials are divided into different classes based on how pure they are. In many cases, an alloy lowers the quality of the material and makes it impossible to use again referred to as downcycling. Reducing the downcycling of different types of metals is incredibly important in order to maintain the value of them, which is an important aspect of the circular economy (Naturskyddsföreningen, 2021).

There are many different ways to join different materials and components, such as glue, screws, welding etc. These assemblies are suitable for different purposes depending on the requirements of a product. For example, if a product needs to be waterproof, tight assemblies are required that are not as easy to separate. But these assemblies determine the possibility of separating the different materials at the end-of-life of the product, and thus also determine the quality of the recycling stream (van Schaik & Reuter, 2009).

Despite a good, elaborate product design that follows DfR guidelines, the guidelines still need to be combined with other types of strategies. It has been proven for some products that the design does not affect the outcome of the material recycling, even if you make them easier to disassemble manually. In order to improve the recycling of materials, several actors are required to cooperate. Recycling depends on the correct collection of waste (such as e-waste) where a sufficient amount needs to be collected for it to become economically favorable for the recyclers, but also the market for secondary materials affects material recovery rates from recyclers. A great design can do much, but in itself it can not do enough to solve the global e-waste problem (Stevels, 2007).

2.6 Product development process

The product development process at Ericsson consists of eight main steps illustrated in Figure 5. The early phases contain two iterative parts, exploratory and portfolio phase. The exploratory phase focuses on exploring new ideas, concepts, technologies and architectures. The portfolio phase focuses on providing input to product plans, development plans and product development. The second step, opportunity analysis, evaluates what needs to be developed and defines the scope including cost estimates. The next step is pre-study where the main activity is to study and evaluate different design concepts with the goal to choose one prefered concept for the upcoming phases. Mechanical designers participate in the critical choices of building practices that are very difficult to change later on in the project process. Mechanical designers present different design concepts evaluated against function, manufacturing cost and supply. Connected to opportunity analysis and pre-study are “define module system” 1 & 2. This process is an addition for radio development and includes setting requirements, technologies and frequencies used for the module system. The next phase is requirement analysis & conceptual design where the main activity is to break down the mechanical concept into a structured design with mechanical parts. The mechanical parts are analyzed regarding environmental requirements, usage and production etc. to ensure that the design will pass verification tests later on in the project process. The following phase is design & design verification preparation and the main activities here are preparations to create a prototype for verification testing, the mechanical design is also evaluated so that it still passes the analyses made in the design preparation phase. The next step is the design verification phase where activities to verify the product takes place to ensure that all requirements are fulfilled. This step is followed by the final documentation & product release phase where all documentation is finalized. The final step in the product development process is the handover to maintenance phase (Ericsson, 2022).

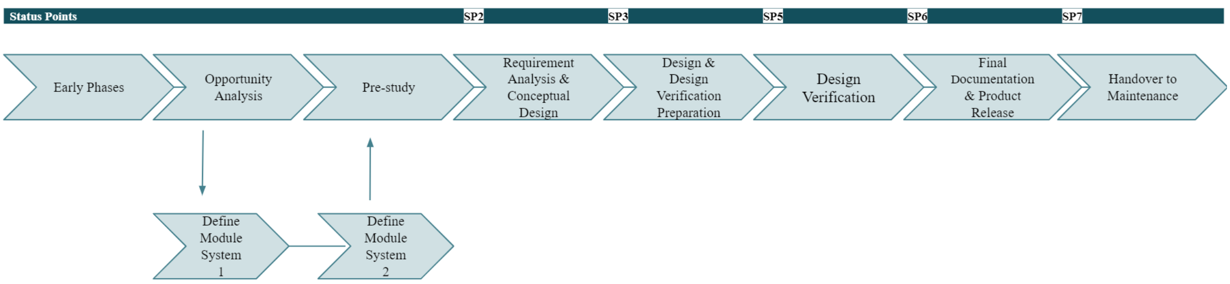

Figure 5. Illustration of the product development process at Ericsson.

Issues related to sustainable product design should be considered as early as possible in the design process. If these aspects are considered early on in the concept and feasibility stages it will pay dividends and avoid the need for design changes later on in the design process that would be more expensive (Envirowise, 2004).

In this chapter, the study´s approach and structure is presented. Furthermore, the secondary data collection and primary data collection is described. Details about which respondents participated in the study are described under each section where qualitative or quantitative data has been collected. Finally, the implementation of product evaluation and a section regarding the quality measures in the study are presented.

3.1 Study approach

The method is divided into a secondary data collection and a primary data collection, which is followed by a product evaluation. The secondary data collection phase includes a literature review and analysis of Ericsson's DfE Guidelines. Furthermore, it is followed by the primary data collection phase that includes a site visit, expert interviews, a survey, interviews with product designers employed at Ericsson and a workshop. For an illustrated overview of the method, see Figure 6.

The study approach is a mixed method where the combination and integration of quantitative and qualitative methods are used. The survey evaluation of guidelines represents the quantitative method and the interviews and site visit represents the qualitative method. The main purpose of using both methods in the same study is that qualitative and quantitative approaches in combination provides a better understanding of complex research problems than either approach used alone (Creswell & Plano Clark, 2011).

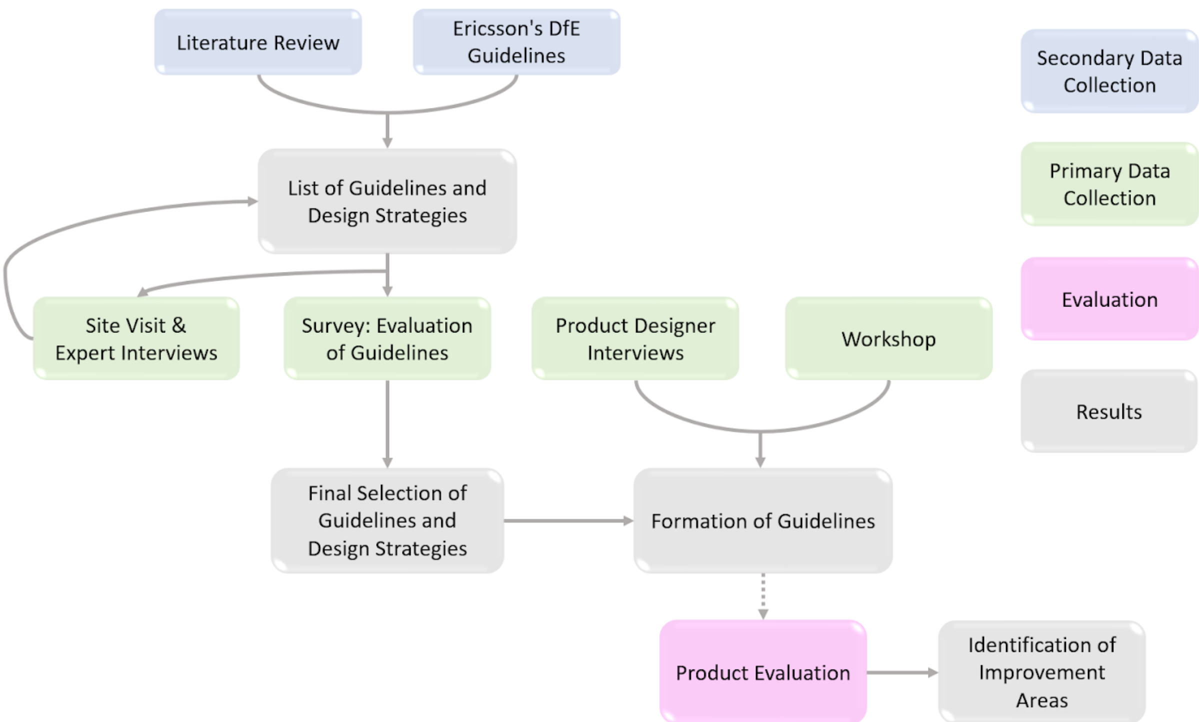

Figure 6. Overview of the study´s approach.

3.2 Secondary data collection

In order to update and extend Ericssons current DfE guidelines, the study started with a collection of secondary data regarding various DfR guidelines and design strategies. The secondary research includes a literature review and analysis of Ericssons current DfE guidelines. The usage of secondary data is due to the reason that there are already many studies published regarding design for recyclability with associated guidelines. Secondary data is advantageous to use when there is already a lot of information and data available and can therefore help save time. The time saved can instead be spent on distinguishing and summarizing data (Eneroth, 2005).

3.2.1 Literature review

The web was screened for DfR guidelines relevant to product development of electronic equipment. The collection of data for the literature review was carried out by the usage of reports, journals, books, articles and websites found through the databases google scholar, KTH Primo, google search and wiley. Keywords that were used during the search of DfR guidelines were: design for recycling, recycling strategies, recyclability, circular design and e-waste.

The guidelines that were found during the literature review were copied into an excel document to provide a better overview to facilitate the analysis. The search for guidelines continued as long as new guidelines were found. When similar guidelines began to appear more frequently, saturation was reached. The guidelines were further divided into different types of categories that were determined after reviewing the collected guidelines. These categories were: *coating, contamination, crushing, fasteners, hazardous substances, materials to avoid, PCB and plastic.* The division into different categories facilitated the screening for duplicates and similar guidelines.

3.2.2 Ericsson's DfE guidelines

An internal secondary data collection was made to gather and analyze Ericssons current DfE guidelines. The purpose was to get an insight on how they are described and how they are used. Also, the analysis had a purpose to identify gaps and how the DfE guidelines could be improved.

Ericssons DfE guidelines includes 22 guidelines within the categories energy, end of life treatment, materials and packaging. The guidelines were read through carefully and those that had a connection and were relevant for DfR were selected. These guidelines were copied into the excel sheet and divided into categories as described in section 3.2.1. Thereafter, the guidelines were compared with the ones found from the literature review and duplicates were removed.

3.3 Primary data collection

Collection of primary data was needed in order to fill the gap of information from the secondary data collection and to gain an understanding of how Ericsson's products are recycled. This was done by collection of qualitative data in the form of a site visit and interviews with experts working for some of the companies that currently recycle products from Ericsson. Besides, the guidelines identified via secondary data collection were evaluated by a quantitative data collection in the form of a survey. Furthermore, the results from the survey were used to further formulate guidelines to better suit Ericsson and its needs, by pursuing a qualitative data collection through interviews with employees at Ericsson who primarily work with the design of products.

3.3.1 Site visits & Expert interviews - Qualitative data

The site visit was conducted to observe and understand the influence of product design on the recycling process and thereby get a deeper insight into problems encountered when recycling electronics. The original plan involved two site visits to recycling sites that are partners to Ericsson. However, due to unforeseen circumstances it was only possible to conduct one site visit. The site visit was made at NG Metall AB in Katrineholm where a tour of the whole recycling process was made. The tour took 1 hour and during the tour, follow-up questions were asked based on the information provided by the respondents in charge of the tour.

The purpose of the expert interviews was to understand what they see as critical aspects of e-waste management but also to get experts' views on different recycling guidelines found in literature. The interviews were based on an interview guide and were conducted semi-structured. The interview guide was organized based on various themes concerning processes, material, assembly methods and future trends. The interviews also covered discussions regarding DfR guidelines. A semi-structured interview gives the respondent the opportunity to express themselves freely about the questions and opens up the opportunity to contribute with additional supplements that benefit the work (Denscombe, 2017). A semi-structured interview also means that the questions can be asked in the order that comes naturally during the interview.

Table 2 shows a summary of the interviewed respondents, their roles and details about the interviews. Interviews were conducted with five respondents and they were selected based on their level of experience within e-waste recycling. The length of the interviews varied between 25-50 minutes. Two interviews were conducted individually through Microsoft Teams and one interview was conducted in a group setting with three respondents. The group interview was documented by taking notes and the individual interviews were documented by audio recording and notes.

Table 2. Summary of the interviewed respondents.

Respondent	Role, Company, Location	Type of interview	Time (min)	Documentation
Respondent 1	Business Project Manager, Ragn-Sells Recycling AB, Visby	Microsoft Teams	25	Audio recording & notes
Respondent 2	SHEC Manager, NG Metall AB, Katrineholm	Group interview, on site in Katrineholm	50	Notes
Respondent 3	Marketing and Sales Manager, NG Metall AB, Katrineholm			
Respondent 4	Business Development Manager, Li-Tong Group			
Respondent 5	Director of Operations, Re-Teck, Dallas	Microsoft Teams	35	Audio recording & notes

3.3.2 Survey - Quantitative data

The purpose of the survey was to get a better understanding of recyclers perspective on the identified guidelines from the secondary data collection. The survey consisted of 38 guidelines followed by three complementary questions.

Every guideline in the survey was rated with a 1-5 Likert scale where the respondents got to evaluate each one where 1 corresponded to ''no importance'' and 5 ''high importance''. The reason to use a Likert scale was to be able to easily compare answers and to enable the calculation of an average value of each answer, as well as to see how the spread of the answers would be (MacRae, 1966). The respondents were asked to evaluate the guidelines with regards to their own recycling process. The three complementary questions asked at the end of the survey were:

- Are there any of these guidelines you would like to add a comment to? Please motivate
- Do you have any other guidelines/thoughts in mind that you think is important to include?
- Which company do you work for?

The questions were asked to make sure that every important aspect and thought were covered. None of the questions nor the rating of guidelines were mandatory to answer. The respondents were encouraged to only evaluate guidelines in their area of expertise to make sure that the received answers were well-grounded. The survey was distributed to 10 persons at various recycling companies, both through Ericssons partners and other recycling companies handling e-waste and received 6 responses.

It was decided that guidelines that receive an average score of 3 and above would be seen as important and selected for further development and evaluation.

3.3.3 Product designer interviews - Qualitative data

The purpose with the product designer interviews was to gain an overview of the product development process and when typical design decisions are made. The interviews also examined the current use of DfE guidelines and how new guidelines should be formulated so that they meet the designers needs. The interviews were based on an interview guide and were conducted semi-structured. The interview guide was organized based on various themes concerning the product development process and practical use of guidelines to provide an insight in those specific areas. Interviews were conducted with four respondents from the three mechanical design departments at Ericsson. The respondents were selected based on their level of experience and their areas of responsibility in the product development process. The respondents represented different parts of the process, which gave a broad insight.

The length of the interviews varied between 15-55 minutes and were conducted individually with each respondent through Microsoft Teams. The interviews were recorded and notes were taken during the session. Table 3 shows a summary of the interviewed respondents.

Table 3. Summary of the interviewed respondents.

Respondent	Role	Type of interview	Time (min)	Documentation
Respondent 6	Senior Developer Mechanical Design	Microsoft Teams	36	Audio recording & notes
Respondent 7	Senior Developer Mechanical Design	Microsoft Teams	55	Audio recording & notes
Respondent 8	Senior Developer Mechanical Design	Microsoft Teams	29	Audio recording & notes
Respondent 9	Master Developer Mechanical Design	Microsoft Teams	15	Audio recording & notes

3.3.4 Workshop - Qualitative data

A workshop was conducted to gather input from Ericsson employees who will be working with these guidelines in the product development. In a workshop, issues can be presented, experimented with and discussed with participants. This is an opportunity to identify new factors to the content of the workshop, which neither the participants nor the researchers may not have been aware of prior to the workshop (Ørngreen & Levinsen, 2017).

The workshop took place during one of Ericsson's global meetings. The meeting was conducted via Microsoft Teams where 16 employees from different departments and countries participated. An Excel file was sent to the participants one week before the meeting so that they would have time to go through the guidelines before the meeting and thus be prepared. The workshop lasted for about 50 minutes where the time was divided into two parts. During the first part of the workshop the progression of the project was presented for about 20 minutes to inform the background to why the work is carried out, where the guidelines come from, and what remaining work there is in the study. The remaining time was spent discussing the Excel document with the guidelines in breakout rooms, where the participants were divided into 5 different groups with about 3 people in each room. Each group had to appoint a person who would be responsible for writing notes in the Excel document during the discussions. Participants were encouraged to discuss the following issues in relation to the guidelines:

- Can they be fulfilled?
- Are they difficult to understand?
- Is the motivation behind each enough?
- Other thoughts or reflections?

The person in charge in each group was encouraged to email the notes they wrote down. Furthermore, all comments from the different groups were compiled in an excel document to get a better overview. From there, the answers were analyzed to review what corrections might need to be made.

3.4 Product evaluation

After the list of final guidelines were completed, a product evaluation was performed. This involved evaluation of some of Ericsson's existing products against the guidelines to see how they stand in the current situation and also to identify potential areas for improvement. The evaluation was performed on 3 different products within Ericsson's radio system portfolio together with 3 respondents who have broad knowledge of each product's design. For a summary of the meetings, see Table 4.

Table 4. Summary of the interviewed respondents.

Product	Respondent	Role	Place	Time (min)
1	Respondent 10	Industrial Design Engineer	Microsoft Teams	65
2	Respondent 11	Senior Developer Mechanical Design	Microsoft Teams	45
3	Respondent 12	Senior Developer Mechanical Design	Microsoft Teams	50

During the meeting, all guidelines were discussed one by one to answer which guidelines are fulfilled, not fulfilled and partially fulfilled. Each guideline was color-coded to easily get an overview of the results. The guidelines that the product fulfilled were coded in green and those that were not fulfilled were coded in red. The guidelines that were partially fulfilled were coded in orange and the questions that the respondent could not answer were left blank. The ones that were left blank were summarized in an excel sheet and sent via Microsoft Teams to two additional respondents knowledgeable in each area to obtain a complete, accurate product evaluation. For a summary of the additional respondents, see Table 5.

Table 5. Summary of the interviewed respondents.

Product	Respondent	Role	Place
1, 2 & 3	Respondent 13	Senior Developer Material Technology	Microsoft Teams
1, 2 & 3	Respondent 14	Developer	Microsoft Teams

4 RESULTS

In this chapter, the result of the study is presented. Firstly, the secondary data collection findings are presented that include guidelines found in literature and Ericsson. The primary data collection findings are presented including interviews, site visit, survey and workshop. Furthermore, the final selection of guidelines are presented and finally the result of the product evaluation is presented.

4.1 Secondary data collection findings

In this section the results from the secondary data collection are presented. It includes two partial results consisting of findings from the literature review and the overview of Ericssons Design for Environment document.

4.1.1 Existing guidelines from literature

During the literature review, it was mainly two documents that stood out and proved to have good insight into DfR. These documents contained clear guidelines with supporting justification as to why they are important to adapt.

The document ‘’Guidelines and Design Strategies for Improved Product Recyclability’’ is a master thesis report written by Natalie Hultgren (2012) where she conducted a study at the electronics company Philips. In this study, several design strategies are developed that focus on recycling for electronic products. These guidelines are developed through a literature review, interviews, survey and a product test at Philips. The second document ‘’Circular Design Guidelines’’ was written by Thijs Feenstra et.al. (2021) and is the result of a research that consisted of guidelines aimed at life cycle thinking of plastics and precious metals in electronics. These guidelines are taken and compiled from a number of published articles and reports. These documents together contain guidelines that cover which materials and material combinations should be avoided, assembly methods and design strategies. In addition to these, 3 guidelines were added, two from the Cadence website (n.d.) and one from the document ‘’Guidelines for designing for disassembly and recycling’’ written by Tracy Dowie and Matthew Simon (1994). A total of 31 unique guidelines were found. These guidelines are presented below in Table 6.

Table 6. Guidelines found in literature.

No	Recommendation	Motivation	Source
1	Do not use any BFR’s (Brominated Flame Retardants; PBDEs, TBBPA, PBBs, HBCDs, etc.) in the product. Make it 100% BFR-free	These substances are likely to be restricted in the future	Hultgren
2	Use click/snap solutions to fix valuable components (PCBs, cables, wires and motors) in a product. Avoid permanent fixing such as glued, welded and enclosed solutions.	Designers are advised not to glue valuable components together but to choose for click/snap-solutions to enable easy removal. If the valuable components are easier to take out it contributes to less negative health and environmental impacts. It also has a positive impact in controlled recycling, since if the valuable materials can be easily separated, less of it gets lost into other material streams and more can be recycled into new materials	Hultgren & Feenstra et.al.
3	Use a module for hazardous components	To use one module where all the hazardous components	Hultgren

	in the product structure to enable taking out one non-recyclable module instead of searching for several different hazardous parts.	are located makes the recycling process easier and more efficient. It is easier for the recycling workers to find one module in the manual dismantling step instead of taking time to find several components. It saves time and effort in the process which reduces costs significantly	& Feenstra et.al.
4	Do not use coatings on plastics such as painting, lacquering, plating, and galvanizing, since it can result in changed density of the plastic.	Avoid coatings if possible since all forms of coatings pollute the material streams or makes the recycling process difficult. Coatings change the density of the plastics, which makes it likely to end up in the wrong material stream. The coating material itself also pollutes the streams. Printing of numbers or lines for level-indication (which are small compared to the product as a whole) are not a problem, in fact that is better than using a sticker for the same purpose.	Hultgren & Feenstra et.al.
5	Do not use elastomers. When elastomers are necessary, use elastomers with a different density than the common recycled plastics (not in the density range of PP, PE, PS and ABS which is 0.888e3 – 1.070e3 kg/m3)	Elastomers are not (currently) possible to recycle, and are either burned or end up polluting material streams. If elastomers are necessary, use a density that is different from common plastics, since then the elastomer will end up polluting the material streams of these plastics. The separation of plastics and similar materials is done by density separation, usually in various floatation steps. The density will therefore determine which recycling stream the plastic ends up in.	Hultgren
6	Do not mold different material types together by 2K or xK processes (different plastic materials injected into the same mould) such as molding a thermoplastic elastomeronto PP (e.g. toothbrush). If the material types are the same and only differ in colour and additives it is ok to use, for example molding red PP containing antioxidants on black PP containing talc.	Avoid molding different material types together since the end result will not be recyclable. It is very difficult to separate materials that have been joined by 2K or xK processes. Therefore these joined materials will end up as waste or (depending on density) they will pollute other plastic streams	Hultgren & Feenstra et.al.
7	Do not permanently fix Aluminum, Copper (including Brass), Stainless steel or Steel together in the following combinations: - If the main material in a component is Al (cast), do not attach a part of Stainless steel or Steel onto it. - If the main material in a component is Al (wrought), do not attach a part of Al (cast), Copper, Stainless steel or Steel onto it. - If the main material in a component is Stainless steel, do not attach a part of Copper onto it. - If the main material in a component is Steel, do not attach a part of Copper or Stainless steel onto it. - If the main material is Copper, do not permanently fix a part of Iron, Lead, Antimony or Bismuth to it.	These combinations are based on thermodynamical properties of the materials, indicating which materials are feasible to combine and which ones are not. Depending on the main material in a component, smaller amounts of other materials will end up polluting that stream. Some materials are easy to separate while some are very problematic. A good and easily separable material combination will result in streams that are less contaminated as well as less waste, since many streams containing a pollutant that is hard to extract will simply end up as a waste fraction. This list should also be considered when selecting fasteners.	Hultgren & Feenstra et.al.
8	Do not use connections that enclose a material permanently. Avoid methods such as: molding-in inserts into plastic,	To avoid using connections that enclose a material permanently helps to avoid polluting the material streams. Enclosing a material permanently makes it harder to	Hultgren & Feenstra

	rivets, staples, press-fit, bolts, bolt and nut, brazing, welding and clinching.	separate the different materials. The processes mentioned are typical for tightly enclosing one material into another, and are therefore recommended to be avoided	et.al.
9	Avoid use of foam	When foam is necessary, use thermoplastic foam. Do not use elastomers or thermosets for foam.	Feenstra et.al.
10	Avoid thermosets	Thermosets are not (currently) possible to recycle, and are either burned or end up polluting material streams, thereby relevant for the recycling process. When thermosets are necessary, use thermosets outside the density range of 0.85 – 1.25 g/cm3 (range of the common recycled plastics).	Feenstra et.al.
11	When thermosets are necessary, use thermosets with a different density than the common recycled plastics.	The separation of plastics is done by density separation, usually in various flotation steps. The density will therefore determine which recycling stream the plastic ends up in, thereby relevant for the recycling process.	Hultgren
12	Minimize the use of thermoplastic elastomers.	Thermoplastic elastomers are not recycled. Therefore they have to be separated. Particles that are not separated can be seen as a pollutant.	Feenstra et.al.
13	When elastomers are necessary, use elastomers with a different density than the common recycled plastics.	The separation of plastics and similar materials is done by density separation, usually in various floatation steps. The density will therefore determine which recycling stream the plastic ends up in, thereby relevant for the recycling process.	Hultgren
14	Minimize the use of magnets	Magnets will end up in the ferrous material stream, polluting it.	Feenstra et.al.
15	Do not use composites	They end up in burning, landfill or polluting other fractions since the different materials in the composite cannot be separated. Relevant for the recycling process.	Hultgren
16	Do not use polymer blends.	Polymer blends are generally very hard to separate, and therefore end up either being burned or polluting the material streams. Relevant for the recycling process. Mono material streams should be the goal. Blends like POM/ABS, PA/ABS, PC/PBT, PPE/PS, PET/PBT pollute material streams. (except for PC/ABS, as this can be recycled well	Hultgren
17	Do not use more than 5% master batch in plastics.	The more master batch in the plastic, the more polluted the material streams of the plastics will become. To avoid pollution of the streams, as low concentration as possible is preferred, with a maximum limit of 5%. This is important today but also for the future, since stricter legislation on the concentrations in plastic recycling streams can be expected. This means that a plastic stream that has too high concentration of certain substances cannot be used as recycled plastics, but will instead be burned. Higher concentration of master batch also often means more hazardous fumes from burning.	Hultgren
18	Do not choose fasteners made of materials not compatible with the connecting components.	The fastener often ends up with the main component it is attached to. If a screw is attached to plastic, then either the plastic part will go into the metal stream or the screw will end up in the plastic stream.	Hultgren
19	When using metals, ensure the ferrous metals used are magnetic. Ensure the non-ferrous metals used are non-magnetic.	To prevent metals end up in the wrong metal fraction.	Hultgren

20	Prefer snap-fits for plastic components whenever technical possible.	Plastic snap-fits usually make it easy to remove the housing and open up the product, since they break and the housing is often cracked open in the first dismantling step. This helps the workers since they do not need to break open the product themselves. Plastic snap-fits are also an upside in case the product goes straight into the shredder; they will then follow the plastic host component into the plastic stream. With a metal screw there is for example always a risk that it goes either with a plastic part into the plastic stream or that a plastic part goes with the screw into the metal stream.	Hultgren
21	Do not fix ferro to non-ferro, concerns parts as well as fasteners	If ferro and non-ferro materials are joined and the product goes into shredding it is very likely that either the ferro or the non-ferro stream will be polluted.	Hultgren & Feenstra et.al.
22	Ensure the hardness of all components is compatible with shredding process. Maximum 59HRC (Hardness Rockwell Cone)	Ensure the hardness of all components is compatible with shredding process. Maximum 59HRC (Hardness Rockwell Cone)	Hultgren
23	If a component exceeds max hardness for shredding process, enable fast and easy removal of the component. Provide detachment possibilities, and ensure that they can be detected and accessed easily.		Hultgren
24	Minimize the number of fasteners removal tools required	Changing tools cost time	Tracy Dowie & Matthew Simon
25	Use smaller more compact board design		Cadence
26	Minimize the number of fasteners or connectors		Cadence
27	Use only common plastics in the product such as ABS, MABS, PE, PP, PA, PC, PC/ABS, HIPS.	Common plastics can easily be recycled and should always be used as a first choice. If another material is needed ensure the reasons are motivated and supported. There are established recycling streams for these plastics, which means that they very likely will be recycled. Other materials currently occur in too small volumes in the waste stream to make it economically viable to recycle them. Background: When other than these common plastics are used, choose plastics outside the density range of 0.85 - 1.25 g/cm3.	Hultgren & Feenstra et.al.
28	Avoid glass fiber filled plastics.	Glass fibers pollute material streams, reducing mechanical properties and cause wear. Background: Instead of using glass fibers to increase the modulus, use carbon fiber or mineral filled plastics, e.g. a PP-talc mineral can be recycled.	Feenstra et.al.
28	Minimize additives in plastic materials.	Additives reduce the purity of the plastic streams. Check the need for additives.	Feenstra et.al.
30	Avoid use of thermoset-rubbers.	Thermoset rubbers cannot be recycled, therefore avoid the use of thermoset-rubbers. In case you do need to use a thermoset-rubber, make it easy separable to avoid polluting other streams.	Feenstra et.al.
31	Avoid magnetic components on PCBs.	PCB’s have many valuable non-ferrous metals. If magnets are placed onto the PCB, the PCB might end up in the ferro stream. In that case the valuable non-ferrous metals are lost and will pollute the ferro stream	Feenstra et.al.

4.1.2 Existing guidelines from Ericsson

Ericsson's current Design for Environment document contains 22 different guidelines regarding energy, end of life treatment, materials and packaging. This document was examined to find guidelines concerning DfR that are not covered by those from the literature review. This examination led to the selection of 7 guidelines as they were connected to end of life treatment and material selection. The majority of the material-related guidelines that Ericsson's documents contained were already covered by the guidelines found during the literature review. The selected guidelines from Ericsson are presented in Table 7 below.

Table 7. Selected guidelines from Ericssons DfE document.

End of Life Treatment & Material			
No	**Application**	**Recommendation**	**Motivation**
32	General	Avoid joints that are hard to disassemble between different materials	Facilitate dismantling
33	General	Put marking related to End Of Life Treatment in a position where it is easily visible during disassembly	End Of Life Treatment cost
34	Metal parts, Plastics	If applicable avoid films, labels, paint and surface treatment on plastics and metals. Not valid for printed circuit boards	Customer requirement
35	Plastics	If labels are used on plastic parts, use the same material in the labels as in the plastic part itself	Customer requirement
36	Machined metal parts	Mark machined metal parts with a weight over 25 grams or larger than 1 dm2 (largest cross-section) with material identification Mark with chemical symbol based designation system according to European EN standard. Aluminum alloys: [SS-EN 1780-2] Stainless steel: [SS-EN 10088-1] Copper alloys: [SS-EN 1982] Zinc alloys: [SS-EN 128 44:1] Note! Do not use labels. Preferably mark by punching.	End of Life Treatment cost
37	Cables	Mark cables with material identification	End of Life Treatment
38	Architecture	Make the system design as modular as possible to support repair and upgrading	Minimize material use

4.2 Primary data collection findings

In this section the results from the primary data collection are presented. It includes three partial results consisting of findings from the site visit, recycling expert interviews, survey evaluation, product designer interviews and workshop.

4.2.1 Findings from expert interviews and site visit

Site visit- Recycling process NG Metall AB
The recycling process at NG Metall AB in Katrineholm is illustrated in Figure 7 and begins with incoming cargo arriving and being scanned for radioactive substances. If the load does not contain any radioactive substances, the load is sorted into different piles. Then the dismantling and sorting process begins where the electrical waste is placed on a belt that carries it through various departments. Large and clumsy metal parts are removed as it can cause problems in the shredding process. Large plastic parts are disassembled and lumped together so that they do not have to go through the shredder. Dangerous, non recyclable parts and valuable components are removed from the products such as glass, batteries, combustibles, PCBs etc. What remains of the products after the dismantling phase goes on to the shredding process where it is shredded to pieces of about 10*10 cm. After the shredding process there are some methods for mechanical separation that take place after each other. Magnetic separation is used to remove ferrous metals such as iron, steel and rare earth metals. Optics is used to detect different materials such as aluminum, copper, brass and plastic. Air pressure then sorts the different detected materials into different bins. At this point, the material that has not been sorted out is shredded again into even smaller pieces and undergoes the same process of magnetic, optical and air pressure separation again as illustrated in Figure 7. After the second round of shredding and mechanical separation, the material is sold to smelters for further processing.

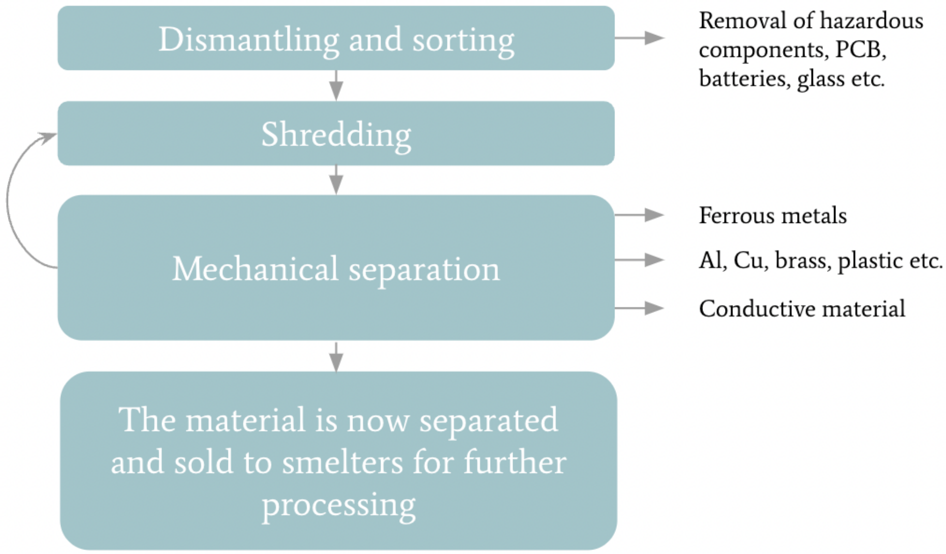

Figure 7. Illustration of the recycling process at NG Metall AB.

When it comes specifically to Ericssons products that go through Ericssons take back programme, those products are first treated individually. Documentation about these products is sent to

Ericsson and in some cases certain components are sent back to the company at the request of Ericsson. Furthermore, the remaining waste passes the mechanical processes described above. Some products on the other hand contain many screws which are labor intensive to disassemble. Therefore, these products are sent to another recycling site in the Baltic states to be disassembled and further processed. In general, all material from Ericssons products is recycled.

Expert interview- Recycling process ReTeck

The other recycler that has been involved in this study, ReTeck in Dallas, has a similar process as NG Metall AB. However, ReTeck has a bigger focus on the disassembly phase in their recycling process. ReTeck receives Ericsson products that have reached end of life, products in need of reparation or products that have been written off the books. This includes products such as radios, antennas, switches, servers etc. Each time a new product is received at the recycling site, they perform an analysis and product breakdown of how much labor that is required in relation to the material value. The analysis is saved so that it can be used to make trade-offs on the same product that is received later. When Ericsson products arrive they are weighed and documented on request of Ericsson. The next step in the process is the sorting phase. The sorting is carried out so that the same types of products can be disassembled at the same time. This is important in order to streamline the process because every time a tool needs to be changed it costs time. Further, the next phase is the disassembly phase where the products are fully disassembled and thereby do not need to go through a shredder. Furthermore the material is sorted into different material streams such as plastic, aluminum, copper etc. After the disassembly phase the material is sorted and ready to be sold to smelters for further processing.

Expert interviews- Important aspects

During the interviews, aspects that the respondents considered to be extra important in the recycling process of electrical waste were discussed. In two of the interviews, including respondent 1, 2, 3 and 4, it was considered important to avoid composites as much as possible and that the use of common plastic is desirable. For example, sandwich-material that contains different layers of material such as fiberglass and epoxy can not be melted again. As a consequence, this ends up in landfill and cannot return in a circular material flow. Another aspect that was shared by all the respondents was that the number and types of screws should be reduced as much as is technically possible. When disassembling products it is very labor intensive to loosen all the screws and on top of that to change tools. The respondents are aware that many screws are required in these types of products, but they would like to point out that it is an important aspect to always consider when developing new products. In two of the interviews, including respondent 1, 2, 3 and 4, it was considered that it is important to avoid glued parts. Glued parts are very difficult to separate and increase the risk of contamination as, for example, metal fractions can follow the plastic stream. Respondent 5 sees press fit as problematic, especially for heat sinks when copper is pressed into aluminum. This is because copper and aluminum must be separated before further processing. If separation of the materials is avoided, it can still be sold as contaminated aluminum, but the value of the copper is so high that separation is prefered. It becomes a consideration whether the time required is worth the potential income. However, respondent 2, 3 and 4 stated that press fit is not problematic for the recycling process. What distinguishes these respondents is that the former respondent disassembles the product completely by hand while the later mentioned respondents let those parts pass the shredding process.

4.2.2 Survey results and evaluation of guidelines

The survey resulted in a total of 6 responses from employees at recycling companies. The mean value for each guideline is presented in Appendix A. Some guidelines have only five answers, which is based on the respondents being asked to only assess the guidelines that were within their area of expertise. Hence, some of the respondents did not evaluate all 38 guidelines. The mean values obtained from the survey of the guidelines were in a range between 3 to 4,5. The purpose of the survey was, as mentioned in section 3.2.2, to remove the guidelines with a mean value below three, and therefore were seen as less important by the recyclers. However, based on the obtained result from the survey, all guidelines have a mean value above three and therefore no guideline can be removed. Hence, all guidelines remain for further evaluation.

At the end of the survey, three questions related to the guidelines were also asked. The first question was if the respondents wanted to add a comment to any of the guidelines. The second question addressed whether they had any other guidelines or thoughts that felt important for them to cover in addition to the presented guidelines. No answers were received to these questions.

The first revision of the guidelines was carried out after the survey. It was not possible to remove any guideline based on the recycler's valuation, as all guidelines were considered as important. However, there were similarities between two guidelines and one guideline that was not intended specifically for DfR. The guidelines 22 and 23 were therefore decided to be merged as they had the same purpose and guideline 23 could be seen as a follow-up to number 22. Guideline 38 was removed as it is not intended specifically for DfR and rather focused on to support maintenance of the product during the user phase. After the first revision of the guidelines they were reduced from 38 to 36.

4.2.3 Product designer interviews and workshop

Product designer interviews

During the product designer interviews, the respondents expressed that they are not actively evaluating the current DfE recommendations in the product development process. Regarding design for environment, there is a greater focus on energy efficiency of the products, banned and restricted materials and ease of disassembly to support repair than end of life treatment such as DfR. However, aspects related to recycling of the product is something the designers have in the back of their mind when developing products. What is seen as most problematic with the guidelines that exist related to DfR is that they are difficult to follow as they are general and open up for individual interpretations.

The respondents expressed that it is important to gain an insight into how the recycling process is done in order to be able to understand the proposed guidelines. A guideline without a motivation as to what consequence there is if not followed is easy to skip due to lack of understanding. Therefore, a motivation for the guideline is important where there is an explanation of why it is relevant and what consequence it has on the recycling process. The respondents also highlighted that the guidelines should be formulated as short and concise as possible as it is difficult and time consuming to read through a long document. Images as well as various options would also help the understanding for product designers working with the guidelines.

During the interviews it was also discussed when in the product development process it is appropriate to review the guidelines. All of the respondents considered that it should be reviewed at an early stage as it becomes difficult and expensive to change the product design in the later stages of the product development process. For example, in the middle of the process when prototypes are built for testing, there are only changes made to the design if the product does not perform the way it is supposed to do. Therefore, in the early phases it is possible to influence a lot on product design and the guidelines should therefore be reviewed before the SP3 phase.

Workshop

During the workshop the guidelines were discussed in five groups of about three respondents. The guidelines were discussed based on the questions if they can be fulfilled, if they are easy to understand, if the motivation behind the guidelines are enough and if other thoughts or reflections come up. Each group did not have enough time to go through all 36 guidelines during the scheduled time. However, the groups were asked to start at different places in the document and in this way, feedback was generated on the majority of the guidelines.

The respondents provided valuable inputs regarding the guidelines. The majority of the guidelines were considered to be clear and that the motivation supporting the guideline was explanatory enough. The guidelines where the respondents considered that the motivation behind being too vague was 1, 8 and 9. For guideline 1 and 9 it was requested that they should include suggestions of replacements as these two guidelines restricted the materials that could be used. For guideline 8 which restricts the use of permanent connections it is desired to include a priority list for the various alternatives presented in the guideline. Some guidelines that were considered difficult to understand were 17 and the merged guidelines 22 and 23. Guideline 17 should include a definition of what master batch is and guideline 22/23 would need to include examples of hardness for different types of material relevant for Ericsson. Throughout the guidelines different formulations were used such as “avoid”, “do not use” and “minimize”. This raised a question among the respondents as to what the difference is between the different formulations. It would be desirable if there would be similar formulations that were used for all guidelines. Further, five guidelines were raised in relation to the question of whether some of the guidelines are difficult to fulfill. This applies to guideline 3, 18, 19, 21 and 34. Guideline 3 which suggests to use a module for hazardous components is difficult to control and implement. Guideline 18 which suggests to not choose fasteners made of materials not compatible with the connecting component is difficult to fulfill. The guideline would need more information regarding what happens in the recycling process. Guideline 19 is difficult to fulfill because both magnetic and non magnetic screws (steel and stainless steel) are used in combination with aluminum chassis and other parts to achieve product requirements. Guideline 21 is difficult to fulfill especially for the radomes and because steel screws are used in aluminum. Guideline 34 is difficult to fulfill as all external parts will always need surface treatment unless another new and innovative corrosion resistant technology is developed. For the radomes it is difficult to avoid surface treatment because it is used as a protection against ice, water and dirt. Without surface treatment on the radomes, the product's performance would decrease significantly. Another reflection that was raised was regarding guideline 25. If the aim is to go towards a smaller board design, it means that there will be more connectors needed and therefore a conflict occurs with guideline 26 that aims to minimize the number of fasteners or connectors.

The second revision of the guidelines was carried out after the workshop. The revision was based on the comments and insights provided by the workshop. Guideline 11 was merged with 10 as they complement each other regarding the use of thermosets. Guideline 13 was removed because it is covered by guideline 5 that contains a broader motivation regarding the use of elastomers. Following the feedback to be consistent with the phrasing, the word “avoid” was changed to “do not use” throughout the guidelines. Guideline 25 creates a conflict with guideline 26 according to comments from the workshop. Since guideline 26 which aims to minimize the number of fasteners and connectors was considered to be very important according to the recyclers, guideline 25 that aims to use a smaller board design was therefore removed. Guideline 3 which suggests to use a module for hazardous components was removed as it is not relevant for radio products and baseband. Guideline 32 about avoiding joints that are hard to disassemble was removed because it is too vague and also covered by other guidelines. Guideline 34 that suggests to avoid films, labels, paint and surface treatment was removed since it is not possible to be fulfilled. The guideline was instead replaced with a new guideline which suggests to not use paint and surface treatment (coating) on metal parts. Guideline 20 was merged with guideline 2 since they complement each other regarding the use of snap-fits. After the second revision of the guidelines they were reduced from 36 to 30.

4.3 Final selection of guidelines

The final result of the collection and revision of the guidelines is shown in Table 8. The table contains 30 guidelines sorted into 3 different categories: *Material & Material Combinations, Fasteners & Connectors and Labels & Markings*. The first section, ‘’Material & Material combinations’’ is further sorted into 2 different categories: *Metal and Plastic*. The guidelines are re-numbered and sorted into different categories in order to facilitate the usage of them. These guidelines have been selected together with experts within recycling in order to facilitate and make the recycling process of Ericssons products more efficient.

Table 8. The final set of guidelines.

No	Guideline	Motivation
1	**Material & Material Combinations**	
1.1	**Metal**	
1.1.1	When using metals, ensure the ferrous metals used are magnetic. Ensure the non-ferrous metals used are non-magnetic.	To prevent metals end up in the wrong metal fraction.
1.1.2	Do not fix ferro to non-ferro, concerns parts as well as fasteners.	If ferro and non-ferro materials are joined and the product goes into shredding it is very likely that either the ferro or the non-ferro stream will be polluted.

No	Guideline	Motivation
1.1.3	Do not permanently fix Aluminum, Copper (including Brass), Stainless steel or Steel together in the following combinations: - If the main material in a component is Al (cast), do not attach a part of Stainless steel or Steel onto it. - If the main material in a component is Al (wrought), do not attach a part of Al (cast), Copper, Stainless steel or Steel onto it. - If the main material in a component is Stainless steel, do not attach a part of Copper onto it. - If the main material in a component is Steel, do not attach a part of Copper or Stainless steel onto it. - If the main material is Copper, do not permanently fix a part of Iron, Lead, Antimony or Bismuth to it.	These combinations are based on thermodynamical properties of the materials, indicating which materials are feasible to combine and which ones are not.Depending on the main material in a component, smaller amounts of other materials will end up polluting that stream. Some materials are easy to separate while some are very problematic. A good and easily separable material combination will result in streams that are less contaminated as well as less waste, since many streams containing a pollutant that is hard to extract will simply end up as a waste fraction.
1.1.4	Do not use paint and surface treatment (coating) on metal parts.	Avoid coatings if possible since all forms of coatings pollute the material streams or makes the recycling process difficult.
1.1.5	Do not use magnets.	Magnets will end up in the ferrous material stream, polluting it.
1.1.6	Do not use magnetic components on PCBs.	PCB's have many valuable non-ferrous metals. If magnets are placed onto the PCB, the PCB might end up in the ferro stream. In that case the valuable non-ferrous metals are lost and will pollute the ferro stream.
1.1.7	Do not use materials with a hardness over 59HRC (Hardness Rockwell Cone). If a component exceeds 59 HRC, enable fast and easy removal of the component. Provide detachment possibilities, and ensure that they can be detected and accessed easily.	Components with a hardness over 59HRC are not compatible with the shredding process.
1.2	**Plastic**	
1.2.1	Do not use any BFR's (Brominated Flame Retardants; PBDEs, TBBPA, PBBs, HBCDs, etc.) in the product. Make it 100% BFR-free.	These substances are likely to be restricted in the future.
1.2.2	Use only common plastics in the product such as ABS, MABS, PE, PP, PA, PC, PC/ABS, HIPS. When other than these common plastics are used, choose plastics outside the density range of 0.85 - 1.25 g/cm3.	Common plastics can easily be recycled and should always to be used as a first choice. There are established recycling streams for these plastics, which means that they very likely will be recycled. Other materials currently occur in too small volumes in the waste stream to make it economically viable to recycle them.

No	Guideline	Motivation
1.2.3	Do not use elastomers. When elastomers are necessary, use elastomers with a different density than the common recycled plastics (not in the density range of PP, PE, PS and ABS which is 0.888e3 – 1.070e3 kg/m3).	The separation of plastics and similar materials is done by density separation, usually in various floatation steps. The density will therefore determine which recycling stream the plastic ends up in. Elastomers are not (currently) possible to recycle, and are either burned or end up polluting material streams.
1.2.4	Do not use thermoplastic elastomers.	Thermoplastic elastomers are not recycled. Therefore they have to be separated. Particles that are not separated can be seen as a pollutant.
1.2.5	Do not use thermosets. When thermosets are necessary, use thermosets outside the density range of 0.85 – 1.25 g/cm3 (range of the common recycled plastics).	Thermosets are not (currently) possible to recycle, and are either burned or end up polluting material streams, thereby relevant for the recycling process. The separation of plastics is done by density separation, usually in various flotation steps. The density will therefore determine which recycling stream the plastic ends up in, thereby relevant for the recycling process.
1.2.6	Do not use thermoset-rubbers.	Thermoset rubbers cannot be recycled, therefore avoid the use of thermoset-rubbers. In case you do need to use a thermoset-rubber, make it easy separable to avoid polluting other streams.
1.2.7	Do not use composites.	They end up in burning, landfill or polluting other fractions since the different materials in the composite cannot be separated. Relevant for the recycling process.
1.2.8	Do not use glass fibre filled plastics. Use carbon fibre or mineral filled plastics instead (e.g. a PP-talc mineral can be recycled).	Glass fibres pollute material streams, reducing mechanical properties and cause wear.
1.2.9	Do not use polymer blends.	Polymer blends are generally very hard to separate, and therefore end up either being burned or polluting the material streams. Relevant for the recycling process. Mono material streams should be the goal. Blends like POM/ABS, PA/ABS, PC/PBT, PPE/PS, PET/PBT pollute material streams. (except for PC/ABS, as this can be recycled well.
1.2.10	Do not use foam. When necessary, use thermoplastic foam. Do not use elastomers or thermosets for foam.	Foam occurs in too small volumes in the waste stream to make it economically viable to recycle. Elastomer and thermoset foam are not possible to recycle.
1.2.11	Do not use coatings on plastics such as painting, lacquering, plating, metallization and galvanizing.	Avoid coatings if possible since all forms of coatings pollute the material streams or makes the recycling process difficult. Coatings change the density of the plastics, which makes it likely to end up in the wrong material stream. The coating material itself also pollutes the streams. Printing of numbers or lines for level-indication (which are small compared to the product as a whole) are not a problem, in fact that is better than using a sticker for the same purpose.
1.2.12	Minimize additives in plastic materials.	Additives reduce the purity of the plastic streams. Check the need for additives.

No	Guideline	Motivation
1.2.13	Do not mold different material types together by 2K or xK processes (different plastic materials injected into the same mould) such as molding a thermoplastic elastomer onto PP. If the material types are the same and only differ in colour and additives it is ok to use, for example molding red PP containing antioxidants on black PP containing talc.	Avoid molding different material types together since the end result will not be recyclable. It is very difficult to separate materials that have been joined by 2K or xK processes. Therefore these joined materials will end up as waste or (depending on density) they will pollute other plastic streams.
1.2.14	Do not use more than 5% master batch in plastics. (Masterbatch is a solid or liquid additive for plastic used for coloring plastics or imparting other properties to plastics).	The more master batch in the plastic, the more polluted the material streams of the plastics will become. To avoid pollution of the streams, as low concentration as possible is preferred, with a maximum limit of 5%. This is important today but also for the future, since stricter legislation on the concentrations in plastic recycling streams can be expected. This means that a plastic stream that has too high concentration of certain substances cannot be used as recycled plastics, but will instead be burned. Higher concentration of master batch also often means more hazardous fumes from burning.
2	**Fasteners & Connectors**	
2.1	Use click/snap solutions to fix components when technically possible. When click/snap solutions are not suitable, screws are ok. **Avoid permanent fixing such as glued, welded and enclosed solutions.**	Designers are advised not to glue valuable components together but to choose for click/snap-solutions to enable easy removal. If the valuable components are easier to take out it contributes to less negative health and environmental impacts. It also has a positive impact in controlled recycling, since if the valuable materials can be easily separated, less of it gets lost into other material streams and more can be recycled into new materials.
2.2	Do not use connections that enclose a material permanently. Avoid methods such as: molding-in inserts into plastic, rivets, staples, press-fit, bolts, bolt and nut, brazing, welding and clinching.	To avoid using connections that enclose a material permanently helps to avoid polluting the material streams. Enclosing a material permanently makes it harder to separate the different materials. The processes mentioned are typical for tightly enclosing one material into another, and are therefore recommended to be avoided.
2.3	Do not choose fasteners made of materials not compatible with the connecting components.	The fastener often ends up with the main component it is attached to. If a screw is attached to plastic, then either the plastic part will go into the metal stream or the screw will end up in the plastic stream.
2.4	Minimize the number of fasteners removal tools required.	Changing tools cost time.
2.5	Minimize the number of fasteners or connectors.	Removal of fasteners cost time.
3	**Labels & Markings**	
3.1	Put marking related to End Of Life Treatment in a position where it is easily visible during disassembly.	Marking that is visible simplifies sorting during the disassembly process.
3.2	If labels are used on plastic parts, use the same material in the labels as in the	Combination of different materials increases the risk of polluting the material streams.

No	Guideline	Motivation
	plastic part itself.	
3.3	Mark machined metal parts with a weight over 25 grams or larger than 1 dm2 (largest cross-section) with material identification. Mark with chemical symbol based designation system according to European EN standard. **Aluminum alloys: [SS-EN 1780-2]** **Stainless steel: [SS-EN 10088-1]** **Copper alloys: [SS-EN 1982]** **Zinc alloys: [SS-EN 128 44:1]** **Note!** Do not use labels. Preferably mark by punching.	Marking that is visible simplifies sorting during the disassembly process.
3.4	Mark cables with material identification.	Marking that is visible simplifies sorting during the disassembly process.

4.4 Product evaluation result

The product evaluation with three of Ericssons existing products is shown in Table 9. The result is based on the respondents knowledge of the products, as well as supplementary information from two additional respondents knowledgeable in materials. The result gives an indication of how these three products fulfill the guidelines today. Green marking means that the guideline is fulfilled, red marking means that the guideline is not fulfilled and orange marking means that the guideline is partially fulfilled.

Table 9. The product evaluation result.

No	Guideline	1	2	3	
1	**Material & Material Combinations**				
1.1	**Metal**				
1.1.1	When using metals, ensure the ferrous metals used are magnetic. Ensure the non-ferrous metals used are non-magnetic.				
1.1.2	Do not fix ferro to non-ferro, concerns parts as well as fasteners.				●
1.1.3	Do not permanently fix Aluminum, Copper (including Brass), Stainless steel or Steel together in the following combinations: - If the main material in a component is Al (cast), do not attach a part of Stainless steel or Steel onto it. - If the main material in a component is Al (wrought), do not attach a part of Al (cast), Copper, Stainless steel or Steel onto it. - If the main material in a component is Stainless steel, do not attach a part of Copper onto it.				●

	- If the main material in a component is Steel, do not attach a part of Copper or Stainless steel onto it. - If the main material is Copper, do not permanently fix a part of Iron, Lead, Antimony or Bismuth to it.				
1.1.4	Do not use paint and surface treatment (coating) on metal parts.				●
1.1.5	Do not use magnets.				
1.1.6	Do not use magnetic components on PCBs.				●
1.1.7	Do not use materials with a hardness over 59HRC (Hardness Rockwell Cone). If a component exceeds 59 HRC, enable fast and easy removal of the component. Provide detachment possibilities, and ensure that they can be detected and accessed easily.				
1.2	**Plastic**				
1.2.1	Do not use any BFR's (Brominated Flame Retardants; PBDEs, TBBPA, PBBs, HBCDs, etc.) in the product. Make it 100% BFR-free.				
1.2.2	Use only common plastics in the product such as ABS, MABS, PE, PP, PA, PC, PC/ABS, HIPS. When other than these common plastics are used, choose plastics outside the density range of 0.85 - 1.25 g/cm3.				
1.2.3	Do not use elastomers. When elastomers are necessary, use elastomers with a different density than the common recycled plastics (not in the density range of PP, PE, PS and ABS which is 0.888e3 – 1.070e3 kg/m3).				◐
1.2.4	Do not use thermoplastic elastomers.				
1.2.5	Do not use thermosets. When thermosets are necessary, use thermosets outside the density range of 0.85 – 1.25 g/cm3 (range of the common recycled plastics).				◐
1.2.6	Do not use thermoset-rubbers.				
1.2.7	Do not use composites.				◐
1.2.8	Do not use glass fibre filled plastics. Use carbon fibre or mineral filled plastics instead (e.g. a PP-talc mineral can be recycled).				◐
1.2.9	Do not use polymer blends.				
1.2.10	Do not use foam. When necessary, use thermoplastic foam. Do not use elastomers or thermosets for foam.				◐
1.2.11	Do not use coatings on plastics such as painting, lacquering, plating, metallization and galvanizing.				
1.2.12	Minimize additives in plastic materials.				
1.2.13	Do not mold different material types together by 2K or xK processes (different plastic materials injected into the same mould) such as molding a thermoplastic elastomer onto PP. If the material types are the same and only differ in colour and additives it is ok to use, for example molding red PP containing antioxidants on black PP containing talc.				
1.2.14	Do not use more than 5% master batch in plastics. (Masterbatch is a solid or liquid additive for plastic used for coloring plastics or imparting other properties to plastics).				
2	**Fasteners & Connectors**				

2.1	Use click/snap solutions to fix components when technically possible. When click/snap solutions are not suitable, screws are ok. **Avoid permanent fixing such as glued, welded and enclosed solutions.**				●
2.2	Do not use connections that enclose a material permanently. Avoid methods such as: molding-in inserts into plastic, rivets, staples, press-fit, bolts, bolt and nut, brazing, welding and clinching.				●
2.3	Do not choose fasteners made of materials not compatible with the connecting components.				●
2.4	Minimize the number of fasteners removal tools required.				
2.5	Minimize the number of fasteners or connectors.				
3	**Labels & Markings**				
3.1	Put marking related to End Of Life Treatment in a position where it is easily visible during disassembly.				
3.2	If labels are used on plastic parts, use the same material in the labels as in the plastic part itself.				
3.3	Mark machined metal parts with a weight over 25 grams or larger than 1 dm2 (largest cross-section) with material identification. Mark with chemical symbol based designation system according to European EN standard. **Aluminum alloys: [SS-EN 1780-2]** **Stainless steel: [SS-EN 10088-1]** **Copper alloys: [SS-EN 1982]** **Zinc alloys: [SS-EN 128 44:1]** **Note!** Do not use labels. Preferably mark by punching.				
3.4	Mark cables with material identification.				

The result includes areas where two or all three of the products do not fulfill certain guidelines. These guidelines are marked with a full circle to the right of Table 9. These areas are therefore classified as areas for improvement. Guideline 1.1.2 is not fulfilled because steel screws are used in aluminum and plastic components and guiding pins in steel are used in aluminum. Guideline 1.1.3 concerning products 1 and 3 is not fulfilled because those products have heat sinks where copper is pressed in aluminum using press-fit. In addition, guiding pins in steel are pressed into aluminum, which is also contrary to the guideline. Regarding 1.1.4, none of the products fulfill the guideline. This guideline is difficult to fulfill according to the respondents as it is a customer requirement and that powder coating protects the metal against corrosion, which is important as the products are exposed to different types of weather conditions. Guideline 1.1.6 is not fulfilled as magnetic components are present on PCBs. Click snap solutions are not used for plastic components, which means that guideline 2.1 is not fulfilled. In addition to this, glue is used to permanently fix certain parts in all three products, for example parts such as overlay and antenna cover. Regarding guideline 2.2, it is not fulfilled since press-fit is used for heat sinks as mentioned previously. Lastly, guideline 2.3 is not met because stainless steel screws are used in aluminum and plastic components.

The result also includes areas where two or all of the products partly fulfill certain guidelines. These guidelines are marked with a half circle to the right of Table 9. These areas are therefore classified as areas for improvement. Guideline 1.2.3 is not fulfilled for any product as elastomers are used for gaskets. The material used is outside the density range, hence the guideline is marked as partly fulfilled. Regarding the guidelines 1.2.5, 1.2.7, 1.2.8 and 1.2.10 these are marked as partially fulfilled for product 1 and 3 since the product's design varies depending on customer and performance requirements. A version of the products has a material with a sandwich structure (composite) containing thermosets, fiberglass and foam and would therefore not fulfill the guideline requirements. However, other versions of the products would fulfill these requirements. Hence the mentioned guidelines are marked as partially fulfilled. Product 1 and 3 also uses foam in another setting than the previously mentioned material, however this foam is a thermoplastic foam which is preferable when necessary.

5 DISCUSSION

In this chapter, the results from the study are compared, analyzed and discussed in relation to the research described in Frame of Reference.

5.1 The purpose of the study

The purpose of the study has been achieved and compared with literature. The current content and usage of the DfE document has been examined. The literature has been examined to find DfR guidelines suitable for EEE. The collected guidelines have been further evaluated together with recyclers' perspectives to provide a set of suitable guidelines for Ericsson's radio system products. A proposal has been given regarding when the guidelines should be used and implemented in the product development process. Finally, a set of Ericsson's products have been evaluated against the guidelines developed and areas for improvement have been highlighted. Some sections from the literature are not covered in the discussion. Since a large part of the literature background includes the guidelines that are evaluated continuously during the study, the discussion focuses to a greater extent on the results. However, the literature that is not covered in the discussion is still important for the holistic understanding of the study.

5.2 The final selection of guidelines

The guidelines were developed to help mechanical designers at Ericsson increase their knowledge and understanding of how different design choices affect the recyclability of products. The guidelines are derived from literature, supplemented with selected recommendations from Ericsson's DfE documents. The final guidelines have been chosen and reformulated after many iterations with both experts in recycling, but also with mechanical designers employed by Ericsson. With the help of these iterations, guidelines have been added, modified and deleted. In comparison with the DfE document, the guidelines developed only contain design strategies within DfR. This is because the focus has been on developing guidelines that will simplify the recycling process and maximize the outcome from it, just like Leal. et.al. (2020) mean is the fundamental idea in DfR. The guidelines concern areas such as material selection, different material combinations and treatments that should not be used, choice of assembly methods and labeling.

Our interview study with the recyclers shows that they are affected to varying degrees by the guidelines, and that there are differences in which guidelines are particularly relevant to them. This depends on what their different recycling processes look like. The respondent from NG Metall in Katrineholm said, for example, that press-fit is something that does not affect the efficiency of their recycling process, as the products are crushed and grinded and thus release the assembly. However, the respondent from ReTech in Dallas thought differently about this, as they focus on separating the products manually. Consequently, 2.2 is a guideline that may have no significance for NG Metall, while it affects the efficiency of ReTech significantly. Furthermore, this resulting set of guidelines are selected to make the product easy to recycle regardless of which site the product ends up in.

The guidelines are carefully selected for Ericsson's radio products, but can arguably be used on other product segments. The respondent from NG Metall said that in general, all material from Ericssons products is recycled because of the high material value they contain. The guidelines may then seem unnecessary from a designer's perspective, but these are not only to increase the recycling rate but also, as previously mentioned, the efficiency of the recycling process. Time-consuming separation costs money, which can make it more profitable for recyclers to transport the products to another site instead, contributing to higher CO2 emissions. This problem was raised by the respondent from NG Metall, who says that they forward Ericsson's products when they contain too many screws. The guidelines can contribute to a more efficient and environmentally friendly recycling by avoiding additional transportation, where the product is fully sorted on a site before it is sent on to smelters. Just as Fifield and Medkova (2016) wrote, implementing DfR strategies can speed up the recycling process.

5.3 Usage and implementation of guidelines

During the interviews with product designers it was clear that the DfE guidelines developed in 2004 were not actively used and evaluated in the product development process. However, the environmental impact is something designers reflect on and try to keep in mind when developing new products. Since e-waste is now the fastest growing waste stream in the world and is currently growing with 3-5% each year according to Cucchiella et. al. (2015) and S. Shittu, D. Williams & J. Shaw (2020), this is truly an important aspect to consider in the product development process. What the respondents considered as problematic with the current guidelines is that they are not sufficiently motivated and therefore open up for individual interpretations which makes them difficult to adapt. In order for the guidelines to be useful they must have a clear motivation but at the same time be kept short and concise. The motivation should include an explanation on how the recycling process is affected so that designers can gain a greater understanding of why the guidelines are important. If this is met, the guidelines can be useful in the product development and thereby benefit the recyclers. It is also important to continuously evaluate the document so that the guidelines stay up to date as the years go by. According to Tansel (2017) it is necessary to design high tech products for ease of disassembly to enable the material recovery process to be feasible. However, it is not only the recyclers that benefit from this. By enabling the material to be circulated efficiently, the pressure on the environment can be reduced and the security of the supply of critical raw materials can be improved in the future. Also, by actively working with these guidelines, Ericsson is increasing its work within sustainability, which can arguably contribute to competitiveness in the future.

Respondents from the interviews with product designers considered it appropriate to consider the guidelines early in the product development process. This opinion is shared with Envirowise (2004) where the authors consider that issues related to product design should be evaluated as early as possible in a design process. Another aspect they share related to why the guidelines should be considered early in the process is that it will be expensive to implement changes to the product design at a later change. More specifically, Envirowise (2004) suggests to consider these aspects in the concept and feasibility stages and the respondents suggest that the guidelines should be reviewed before SP3 where the following phases are considered; “early phases”, “opportunity analysis”, “pre-study” and “Requirement analysis & conceptual design”. By reviewing what these different phases contain for different activities, these guidelines should be reviewed during the pre-study. In this phase, mechanical designers evaluate critical choices of building practices and present different design concepts. In short, the main activity in this phase is to study and evaluate different design concepts with the goal to choose one preferred concept for the upcoming phases.

5.4 Identified areas of improvement

The product evaluation was conducted to review how some of Ericsson's products meet the guidelines today and further to identify areas for improvement. During the evaluation, three different products were evaluated. However, product 3 is designed in a similar way as product 1, so the answers for these products were similar. To get a clearer indication of areas for improvement, more different products would have to be evaluated.

There were two areas that had high potential for improvements, 1.1 Metal and 2 Fasteners & Connectors. However, many of these guidelines are controlled by customer and product requirements for the product to be functional throughout its lifecycle. Ericsson's products are made for complex applications and therefore also require a more complicated construction of different materials to achieve this. Today's technology may not enable all guidelines to be fulfilled, but they may be fulfilled in the future when new technologies and materials are developed. Therefore it is important to strive to reach these guidelines. When it comes specifically to guideline 2.3, it is not fulfilled because screws in steel and stainless steel are used for components made of plastic and aluminum etc. These are not compatible and can end up polluting the material streams if, for example, a screw ends up in the plastic flow. However, according to the respondent from ReTech and NG Metall, the screws are removed before further processing and thus can not end up in the wrong material flow. However, some screws can be missed and thus end up in the wrong flow, so it is still an important guideline to keep in mind during the design process. Furthermore, this guideline is difficult to fulfill, as screws are one of the better assembly methods, and should always be chosen before glue.

For area 3 Labels & Markings, it turned out that all products fulfill these guidelines. However, just because the products fulfill these guidelines today does not make them less important to consider. These guidelines are important for the development of new products to remind designers to continue in the same direction as before. For area 1.2 Plastic, this section hardly contained any red boxes, however, it contained many orange boxes. Most of these orange boxes are due to, as mentioned in the result, that product 1 and 3 have different designs as there are different customer requirements on the radome. The simpler variant contains only thermosets, while the more demanding variant consists of a composite (sandwich material). These guidelines are not fully achievable today due to customer and product requirements that require more advanced solutions. However, it is important to review these to see if these customer and product requirements can be fulfilled via other solutions that simultaneously meet these guidelines.

5.5 Limitations with chosen research method

For the study, it was chosen to collect existing guidelines from literature and other secondary data sources. The advantage of this is to work further with processed guidelines and thereby build on previous research. The risk with this method is that there is a risk that it becomes too focused on only these guidelines and reduces the possibility of developing new guidelines. However, after consideration, the chosen method was considered to contribute to a more useful result for product designers. The collected guidelines are already well motivated and thus they can be further processed instead of starting from scratch by formulating new guidelines.

Initially, the aim of the study was to conduct site visits at two recycling companies and conduct more interviews with experts outside Ericssons organization. As described in section 3.3.1, this could not be done due to unforeseen circumstances. If this had been done, it would have contributed to the study with a broader perspective on several aspects related to the recycling process. One such aspect is to gain a greater insight into what happens to Ericssons products during recycling, but also in order to see what similarities and differences there are in the recycling process for several recycling companies. The insights regarding what recyclers consider important or insignificant related to e-waste recycling would also be strengthened with additional interviews and respondents leading to a broader perspective. There has also been relatively low participation in the survey, which received 6 responses. Therefore, it can be discussed how reliable the survey result is and whether it is reasonable to draw conclusions based on the obtained data. However, the responses from the respondents were quite similar. Hence, an assessment was made that conclusions could be drawn from the survey result. Another reason that supports this is that all respondents on the survey work with recycling of e-waste and are therefore knowledgeable and credible in the subject.

The chosen method to discuss the product evaluation together with respondents who have been a large part of the development of each product has both advantages and disadvantages. The main advantage is that the respondents have good knowledge of the product, which makes the evaluation process simple and smooth. However, there is a disadvantage that should be highlighted. This includes how critical the respondents want to be to the products they have developed and how willing they are to point out any weaknesses in the product design. An alternative to the chosen method would have been to carry out the product evaluation with more respondents responsible for each product. However, this was not possible due to the time frame of the project.

6 CONCLUSION

In this chapter, the conclusions from the study are described. The conclusions are based from the analysis with the intention to answer the main objectives described in section 1.2 Purpose.

The content and usage of the DfE document at Ericsson has been investigated. Our interview study found that the previously developed guidelines from 2004 were not actively used and evaluated in the product development process. However, designers do evaluate the environmental aspect when developing products. The guidelines from 2004 open up for individual interpretations as they are not sufficiently motivated which makes them difficult to adapt and follow. In order to follow such guidelines, they should be clearly motivated and create an understanding of how the recycling process is affected.

Guidelines from the literature and Ericssons DfE document have been evaluated and modified after several iterations with experts in recycling and mechanical designers. The final set of guidelines include 30 guidelines concerning the three following areas; material & material combinations, fasteners & connectors and labels & markings. The guidelines are selected to support the product development of radio products, but they can arguably be used on other product segments at Ericsson.

Recommendations on how the guidelines should be used and implemented in the product development process has been provided. The guidelines should be considered at an early stage in the product development process because it is the optimal phase to influence the product design. Another argument is that changes to the product design later on in the process is expensive to implement. Therefore, the guidelines should be used and implemented during the “pre-study” in Ericson´s product development process. In this phase, mechanical designers evaluate critical choices of building practices and present different design concepts with the goal to choose one preferred concept for the upcoming phases.

An evaluation of how a set of Ericsson´s products currently performs against the guidelines has been made. The product evaluation indicates that there are two areas that have high potential for improvements; 1.1 Metal and 2 Fasteners & Connectors. Several of these guidelines are not fulfilled due to customer and product requirements for the product to be functional throughout its lifecycle. However, they may be fulfilled in the future with new technologies and materials and therefore it is important to strive to reach these guidelines even though it's not possible today. For area 3 Labels & Markings, the products fulfill all guidelines. However, that does not mean they are less important to consider in future product development projects.

7 FUTURE WORK AND RECOMMENDATIONS

This master thesis project has focused on developing updated guidelines, with clear motivations to increase product designers' understanding of different design choices that affects the recycling process. However, the guidelines can further be developed with, for example, proposals for different solutions to be able to meet specific guidelines, as well as suggest which type of solution is considered the best. The guidelines can also be reviewed more together with recyclers in order to make a prioritization order. All guidelines are difficult to meet at the same time, as a solution to one guideline can conflict with another guideline. A priority list could make it easier for designers to decide which guideline they should prioritize over the other.

The proposal regarding when the guidelines should be evaluated in the product development process should be further reviewed. The suggestion is based on interviews with four respondents and may therefore need additional support. In addition, the proposal also means that all guidelines should be reviewed at the same phase in the process, therefore it may also be good to investigate whether certain specific guidelines are better suited to evaluate at some other part of the process. This should also be supplemented with a plan on how these guidelines can best be implemented for continuous use.

This document with guidelines should be continuously reviewed and updated in the future. New recycling techniques may require the document to be modified due to three reasons. Firstly, a certain guideline may no longer be important and can therefore be removed. Second, there can be a need for additional guidelines that this document does not cover. Lastly, existing guidelines may also need to be modified by adding more explanation or examples. Another reason that may require the document to be modified is if new design techniques or materials emerge that need to be evaluated from a recycling perspective.

The guidelines that have been chosen are intended to be used for the product development of new products within the radio system portfolio. These guidelines can arguably be used for other product segments at Ericsson as well. This should be examined whether they are suitable for other segments and how they should otherwise be modified or supplemented to support the product development of other products.

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APPENDIX A: SURVEY RESULT

No	Recommendation	Motivation	Source	No of responses	Mean value
1	Do not use any BFR's (Brominated Flame Retardants; PBDEs, TBBPA, PBBs, HBCDs, etc.) in the product. Make it 100% BFR-free	These substances are likely to be restricted in the future	Hultgren	6	4,33
2	Use click/snap solutions to fix valuable components (PCBs, cables, wires and motors) in a product. Avoid permanent fixing such as glued, welded and enclosed solutions.	Designers are advised not to glue valuable components together but to choose for click/snap-solutions to enable easy removal. If the valuable components are easier to take out it contributes to less negative health and environmental impacts. It also has a positive impact in controlled recycling, since if the valuable materials can be easily separated, less of it gets lost into other material streams and more can be recycled into new materials	Hultgren & Feenstra et.al.	6	4,5
3	Use a module for hazardous components in the product structure to enable taking out one non-recyclable module instead of searching for several different hazardous parts.	To use one module where all the hazardous components are located makes the recycling process easier and more efficient. It is easier for the recycling workers to find one module in the manual dismantling step instead of taking time to find several components. It saves time and effort in the process which reduces costs significantly	Hultgren & Feenstra et.al.	6	4
4	Do not use coatings on plastics such as painting, lacquering, plating, and galvanizing, since it can result in changed density of the plastic.	Avoid coatings if possible since all forms of coatings pollute the material streams or makes the recycling process difficult. Coatings change the density of the plastics, which makes it likely to end up in the wrong material stream. The coating material itself also pollutes the streams. Printing of numbers or lines for level-indication (which are small compared to the product as a whole) are not a problem, in fact that is better than using a sticker for the same purpose.	Hultgren & Feenstra et.al.	6	4,33
5	Do not use elastomers. When elastomers are necessary, use elastomers with a different density than the common recycled plastics (not in the density range of PP, PE, PS and ABS which is 0.888e3 – 1.070e3 kg/m3)	Elastomers are not (currently) possible to recycle, and are either burned or end up polluting material streams. If elastomers are necessary, use a density that is different from common plastics, since then the elastomer will end up polluting the material streams of these plastics. The separation of plastics and similar materials is done by density separation, usually in various floatation steps. The density will therefore determine which recycling stream the plastic ends up in.	Hultgren	6	3,5
6	Do not mold different material types together by 2K or xK processes	Avoid molding different material types together since the end result will not be	Hultgren & Feenstra	5	4,2

	(different plastic materials injected into the same mould) such as molding a thermoplastic elastomeronto PP (e.g. toothbrush). If the material types are the same and only differ in colour and additives it is ok to use, for example molding red PP containing antioxidants on black PP containing talc.	recyclable. It is very difficult to separate materials that have been joined by 2K or xK processes. Therefore these joined materials will end up as waste or (depending on density) they will pollute other plastic streams	et.al.		
7	Do not permanently fix Aluminum, Copper (including Brass), Stainless steel or Steel together in the following combinations: - If the main material in a component is Al (cast), do not attach a part of Stainless steel or Steel onto it. - If the main material in a component is Al (wrought), do not attach a part of Al (cast), Copper, Stainless steel or Steel onto it. - If the main material in a component is Stainless steel, do not attach a part of Copper onto it. - If the main material in a component is Steel, do not attach a part of Copper or Stainless steel onto it. - If the main material is Copper, do not permanently fix a part of Iron, Lead, Antimony or Bismuth to it.	These combinations are based on thermodynamical properties of the materials, indicating which materials are feasible to combine and which ones are not. Depending on the main material in a component, smaller amounts of other materials will end up polluting that stream. Some materials are easy to separate while some are very problematic. A good and easily separable material combination will result in streams that are less contaminated as well as less waste, since many streams containing a pollutant that is hard to extract will simply end up as a waste fraction. The combinations listed here are a shortened version of the full list, adapted to the most used materials in Philips products. This list should also be considered when selecting fasteners.	Hultgren & Feenstra et.al.	6	4,33
8	Do not use connections that enclose a material permanently. Avoid methods such as: molding-in inserts into plastic, rivets, staples, press-fit, bolts, bolt and nut, brazing, welding and clinching.	To avoid using connections that enclose a material permanently helps to avoid polluting the material streams. Enclosing a material permanently makes it harder to separate the different materials. The processes mentioned are typical for tightly enclosing one material into another, and are therefore recommended to be avoided	Hultgren & Feenstra et.al.	6	4
9	Avoid use of foam	When foam is necessary, use thermoplastic foam. Do not use elastomers or thermosets for foam.	Feenstra et.al.	6	3,67
10	Avoid thermosets	Thermosets are not (currently) possible to recycle, and are either burned or end up polluting material streams, thereby relevant for the recycling process. When thermosets are necessary, use thermosets outside the density range of 0.85 – 1.25 g/cm3 (range of the common recycled plastics).	Feenstra et.al.	6	3,67
11	When thermosets are necessary, use	The separation of plastics is done by	Hultgren	6	3,67

	thermosets with a different density than the common recycled plastics.	density separation, usually in various flotation steps. The density will therefore determine which recycling stream the plastic ends up in, thereby relevant for the recycling process.			
12	Minimize the use of thermoplastic elastomers.	Thermoplastic elastomers are not recycled. Therefore they have to be separated. Particles that are not separated can be seen as a pollutant.	Feenstra et.al.	6	3,83
13	When elastomers are necessary, use elastomers with a different density than the common recycled plastics.	The separation of plastics and similar materials is done by density separation, usually in various floatation steps. The density will therefore determine which recycling stream the plastic ends up in, thereby relevant for the recycling process.	Hultgren	6	3,67
14	Minimize the use of magnets	Magnets will end up in the ferrous material stream, polluting it.	Feenstra et.al.	6	3,83
15	Do not use composites	They end up in burning, landfill or polluting other fractions since the different materials in the composite cannot be separated. Relevant for the recycling process.	Hultgren	6	4
16	Do not use polymer blends.	Polymer blends are generally very hard to separate, and therefore end up either being burned or polluting the material streams. Relevant for the recycling process. Mono material streams should be the goal. Blends like POM/ABS, PA/ABS, PC/PBT, PPE/PS, PET/PBT pollute material streams. (except for PC/ABS, as this can be recycled well	Hultgren	6	3,5
17	Do not use more than 5% master batch in plastics.	The more master batch in the plastic, the more polluted the material streams of the plastics will become. To avoid pollution of the streams, as low concentration as possible is preferred, with a maximum limit of 5%. This is important today but also for the future, since stricter legislation on the concentrations in plastic recycling streams can be expected. This means that a plastic stream that has too high concentration of certain substances cannot be used as recycled plastics, but will instead be burned. Higher concentration of master batch also often means more hazardous fumes from burning.	Hultgren	6	3,5
18	Do not choose fasteners made of materials not compatible with the connecting components.	The fastener often ends up with the main component it is attached to. If a screw is attached to plastic, then either the plastic part will go into the metal stream or the screw will end up in the plastic stream.	Hultgren	6	3,83
19	When using metals, ensure the ferrous metals used are magnetic.Ensure the non-ferrous	To prevent metals end up in the wrong metal fraction.	Hultgren	6	3,5

	metals used are non-magnetic.				
20	Prefer snap-fits for plastic components whenever technical possible.	Plastic snap-fits usually make it easy to remove the housing and open up the product, since they break and the housing is often cracked open in the first dismantling step. This helps the workers since they do not need to break open the product themselves. Plastic snap-fits are also an upside in case the product goes straight into the shredder; they will then follow the plastic host component into the plastic stream. With a metal screw there is for example always a risk that it goes either with a plastic part into the plastic stream or that a plastic part goes with the screw into the metal stream.	Hultgren	6	3,67
21	Do not fix ferro to non-ferro, concerns parts as well as fasteners	If ferro and non-ferro materials are joined and the product goes into shredding it is very likely that either the ferro or the non-ferro stream will be polluted.	Hultgren & Feenstra et.al.	6	3,67
22	Ensure the hardness of all components is compatible with shredding process. Maximum 59HRC (Hardness Rockwell Cone)	Ensure the hardness of all components is compatible with shredding process. Maximum 59HRC (Hardness Rockwell Cone)	Hultgren	6	4,17
23	If a component exceeds max hardness for shredding process, enable fast and easy removal of the component. Provide detachment possibilities, and ensure that they can be detected and accessed easily.		Hultgren	6	4,17
24	Minimize the number of fasteners removal tools required	Changing tools cost time	Tracy Dowie & Matthew Simon	5	3,8
25	Use smaller more compact board design		Cadence	6	3,33
26	Minimize the number of fasteners or connectors		Cadence	6	3,33
27	Use only common plastics in the product such as ABS, MABS, PE, PP, PA, PC, PC/ABS, HIPS.	Common plastics can easily be recycled and should always be used as a first choice. If another material is needed ensure the reasons are motivated and supported. There are established recycling streams for these plastics, which means that they very likely will be recycled. Other materials currently occur in too small volumes in the waste stream to make it economically viable to recycle them. Background: When other than these common plastics are used, choose plastics outside the density range of 0.85 - 1.25 g/cm3.	Hultgren & Feenstra et.al.	6	4,5
28	Avoid glass fiber filled plastics.	Glass fibers pollute material streams, reducing mechanical properties and cause wear. Background: Instead of	Feenstra et.al.	6	4,33

		using glass fibers to increase the modulus, use carbon fiber or mineral filled plastics, e.g. a PP-talc mineral can be recycled.			
29	Minimize additives in plastic materials.	Additives reduce the purity of the plastic streams. Check the need for additives.	Feenstra et.al.	6	4,17
30	Avoid use of thermoset-rubbers.	Thermoset rubbers cannot be recycled, therefore avoid the use of thermoset-rubbers. In case you do need to use a thermoset-rubber, make it easy separable to avoid polluting other streams.	Feenstra et.al.	6	3,5
31	Avoid magnetic components on PCBs.	PCB's have many valuable non-ferrous metals. If magnets are placed onto the PCB, the PCB might end up in the ferro stream. In that case the valuable non-ferrous metals are lost and will pollute the ferro stream	Feenstra et.al.	6	4
32	Avoid joints that are hard to disassemble between different materials	Facilitate dismantling	Ericsson	6	3
33	Put marking related to End Of Life Treatment in a position where it is easily visible during disassembly	End Of Life Treatment cost	Ericsson	6	3,83
34	If applicable avoid films, labels, paint and surface treatment on plastics and metals. Not valid for printed circuit boards	Customer requirement	Ericsson	6	3,83
35	If labels are used on plastic parts, use the same material in the labels as in the plastic part itself	Customer requirement	Ericsson	6	3,83
36	Mark machined metal parts with a weight over 25 grams or larger than 1 dm2 (largest cross-section) with material identification Mark with chemical symbol based designation system according to European EN standard. Aluminum alloys: [SS-EN 1780-2] Stainless steel: [SS-EN 10088-1] Copper alloys: [SS-EN 1982] Zinc alloys: [SS-EN 128 44:1] Note! Do not use labels. Preferably mark by punching	End of Life Treatment cost	Ericsson	6	3,33
37	Mark cables with material identification	End of Life Treatment	Ericsson	6	3,33
38	Make the system design as modular as possible to support repair and upgrading	Minimize material use	Ericsson	6	3,83

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